Phelps

NATURAL PHILOSOPHY,

FOR SCHOOLS, FAMILIES, AND PRIVATE STUDENTS.

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Peter Hull.

PREFACE.

THIS work, though based upon the labors of the learned, is not a mere compilation.—The author has endeavored to invest the subject with freshness and interest, to enliven the progress of the young, as they climb the hill of science. We have sometimes paused on our way, to discourse of Him who formed the world, and from whose eternal mind the laws of physical science originated.—Our hearts have been warmed and animated with thoughts of the wisdom and goodness which irradiate every page of the volume of nature.

American parents and teachers; to aid you in your duties, I have labored to prepare this volume. I commit it to you, in the confidence that while it shall impart to your children and pupils the principles of science, it will, at the same time, exert a salutary influence on their moral and religious affections.

In the attempt made to connect religious sentiment with the study of the sciences, I find myself supported by that profound and philosophical writer, Madame Necker De Saussure, from whose second volume on Progressive Education, the following is an extract. "Religion alone unites and connects the various departments of education, external objects with the affections of the heart, the laws of physics with the laws of mind; it is the influence of religion only which can cause science and duty to meet in the same point. What relation, merely human, could we, for example, find between two subjects in appearance so foreign from each other, as those of *physical phenomena*, and the *moral obligations* imposed on man? and yet a connection exists; they have one common source. One God, the sovereign legislator of nature and the soul, wills the reign of universal order. He has subjected matter to the laws of an irresistible necessity, and he has imposed on the free agent, man, a necessity which, though it appears less imperious, forces his will by bitter experience of the evils attached to a neglect of duty. When the creations, and laws of one discerning mind, present themselves on every side, and in the government of the universe, numerous relations are seen to exist between the different departments

of knowledge. To the subjects most fitted to exercise the talent of investigation inherent in the mind of man, are connected objects which appear chiefly fitted to his physical wants, and even those which seem created but to please his imagination. If God is the *eternal geometrician*, who has calculated with exactitude the measure of the different forces in the universe, if he is the *wise legislator* who has engraven his laws upon our souls, if he is the *supreme artist*, who has spread forth beauty upon the earth and in the heavens, and has rendered us sensible to its charms; and as there is nothing in the physical world which is not the immediate work of God, and nothing in the moral world, which does not result from faculties with which he has endowed man, there can be neither object nor thought, which may not be connected with God. Thus all may be linked together, all may harmonize; ideas, before insulated, unite in the mind of the pupil; he views creation as a whole;—*and as soon as he perceives the unity of design in nature, his reason, though still feeble, presents some resemblance to the Supreme reason which conceived the design.*"

To Teachers, I would most solemnly affirm as the result of my experience in education, that the only effectual method of improving the characters of pupils is through the influence of *religious truths*;—and that intellectual culture may be so conducted as to lend most important aid in the great work of *Christian* Education, which should be the Alpha and Omega, the beginning and end of life.

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NOTE.—The matter in small type may be omitted by younger pupils, or at the first going over with the work, as also at public examinations.

FAMILIAR LECTURES

ON

NATURAL PHILOSOPHY.

PART I.

OF MATTER AND ITS MECHANICAL PROPERTIES.

LECTURE I.

INTRODUCTION.

OF THE OBJECTS AND ADVANTAGES OF SCIENCE.

1. NATURAL PHILOSOPHY, recommends itself to attention both for its *influence* on *the mind*, and for its *practical utility*.

2. The *habit of study* is of great importance. No one can ever arrive at eminence, or indeed be well prepared for the ordinary duties of life, who cannot fix his mind steadily upon a subject, and follow out a train of reasoning. Such studies as require close reasoning, and consecutive thinking, are to be recommended *for their influence on the mind*, apart from their other advantages. Among this class of studies, none holds a higher rank than Natural Philosophy. Every young person should seek to apply himself to such pursuits as will strengthen his mind and invigorate his understanding. If he would have his mental faculties bright and active, he must use them.

3. The *love of knowledge is a principle of our nature.* To feel ourselves becoming wiser, more assimilated to the great minds which have instructed mankind, and better able to see the plan and harmony of the creation, seems to add dignity to our own minds. There are, in such feelings and perceptions, enjoyments

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1. Two recommendations of the study of Natural Philosophy.
2. Habit of study. Why Natural Philosophy is useful in its effects on the mind.
3. Dignity and Pleasures of knowledge.

which may be vainly sought, in amusements that neither elevate nor refine our nature. "He who is accustomed to trace the operation of general causes, and the exemplification of general laws," says Herschel, "walks in the midst of wonders unknown to the ignorant, and unseen by the uninquiring eye; every object that falls in his way elucidates some principle, affords some instruction, and impresses him with a sense of harmony and order. Nor is it a mere passive pleasure which is thus communicated. A thousand questions are continually arising in his mind, a thousand subjects of inquiry presenting themselves, which keep his faculties in constant exercise, and his thoughts perpetually on the wing, so that lassitude is excluded from his life; and that craving after artificial excitement and dissipation of mind, which leads so many into frivolous, unworthy and destructive pursuits, is altogether eradicated from his bosom."

4. *Knowledge is power.* It is this that gives to civilized man his advantage over the savage. It is knowledge which guides the arts that minister to the comforts of domestic life, directs the mechanic in the fabrication of articles of convenience and luxury, and presides over the operations of war. It has been said, that "if a man have but a pot to boil, he may learn from science, lessons that will enable him to cook his morsel better, save his fuel, and both vary his dish and improve it." A knowledge of the principles of science, not only renders the man who labors for his bread more skilful and expert in his occupation, but gives him an opportunity while making improvements in the arts, to make new discoveries in Philosophy.

5. The *study of nature* leads us to a more *intimate communion* with the *Great Author of Nature.* We follow his footsteps, we behold the works of his hand, and we learn the laws by which he governs the material world. What pursuit can be more noble, what better fitted to engage the attention and delight the heart of the philosopher and christian?

6. The term *Philosophy* means *a knowledge of the reasons,* or causes of things. A knowledge of these causes leads to important inventions. Every one is familiar with the fact, that the lid of a tea-kettle is forced upward when water is boiling violently within: yet, some grow old without ever thinking *why* this takes place.— An observing mind, while reflecting upon it, would perceive that water acted upon by heat passes into steam or vapor, and that the latter by its expansive force, raises the lid of the kettle.

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4. Power derived from knowledge.
5. To what does the study of Nature lead?
6. Meaning of the term, Philosophy. Steps by which inventions are made.

Having ascertained this power of steam, he might then imagine how it could be applied to machinery, and thus proceed to invent a steam engine. By similar steps have those proceeded who have subjected the powers of nature to the control of man, and, by thus contributing to the comfort and prosperity of society, have enrolled their names among its benefactors.

7. The term, Philosophy of Nature, usually called Natural Science, has an extended signification, including Chemistry which considers the elements of substances, and Natural History which observes their *forms* and *external organs*.

8. Chemistry and Natural Philosophy may be considered as bearing a similar relation to each other as do the microscope and telescope; the former looks at objects near by and scrutinizes their minutest parts; while the latter takes a more general survey and operates upon a much broader scale.

9. Some knowledge of *all* the Natural Sciences is of great importance to the young. Attainments in any one, must facilitate the study of the others. In the study of Natural Philosophy, besides the advantages which may be expected in cultivating the powers of memory, reasoning, and observation, the mind is enlarged by new views of that Infinite Wisdom which has so nicely balanced the powers of nature, that all material things, whether atoms, systems, or worlds, are retained in their proper places, even by the very action of forces which tend to draw them in opposite directions.

10. The Almighty Creator has brought into existence two very different classes of substances, *mind* and *matter*. Every thing we know, or of which we can conceive, belongs to one or the other of these great divisions. There must be one Being in the universe who has always existed, because neither mind nor matter could have created itself. This self-existent, uncreated Being, the Author of all things, is God. In our own persons, mind and matter are connected by a common tie which we call life. The brute creation have a lower order of mind called instinct, by means of which they accomplish their distinct ends. Plants have a living principle but are incapable of action. Stones, wood, water, and air, are matter uncombined with mind; hey have neither soul nor instincts, and possess no principle of life.

11. Natural Philosophy is *the study of matter with respect to its general properties and the laws by which it is governed.*

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7. Difference between the Philosophy of Nature and Natural Philosophy.
8. Natural Philosophy and Chemistry compared.
9. Importance of all the Natural Sciences.
10. Mind and Matter. Argument for the existence of Deity. Life. Instinct. Inanimate objects.
11. What is Natural Philosophy?

12. This science is founded on *observation and experiment;* that is, it admits no principle which is not the result of careful and attentive observation, and which may not be tested by actual experiment.

13. *Matter* is the subject of the science, and *mind* the instrument by which its operations are carried on. By means of the senses, which are, themselves, subject to the will of the soul or mind, the latter becomes acquainted with objects external to itself.

14. We may then define matter to be *that which acts upon any of our senses,* either immediately, or by means of its effects on other bodies. Each of the senses gives information of certain properties of matter, the existence of which we could never have learned from any other source.

To the sense of touch or feeling, we owe our ideas of the softness or hardness, and the length and breadth of bodies. Sight gives us ideas of color; without this sense we could have no conception of the effects of light, as seen in a picture, rainbow or cloud. We might, from feeling, learn to distinguish a square from a sphere or a cylinder, and acquire general notions of figure and extension, but could never have any idea of the variety of forms which are presented in a natural landscape, where rocks, trees. brooks and meadows are grouped together in a picturesque assemblage. A blind person might, by feeling, gain some idea of the magnitude and figure of a church, but he could have no conception of the beauty of architectural proportion.

15. When, on entering an apartment, or walking in a garden, we perceive the odor peculiar to a rose, we believe this flower to be near us. When we hear a flute or a gun, we believe in the existence of an instrument which caused the sound, and should any one tell us that the odor or sound proceeded from *nothing,* we should know this to be false.

16. The *cause of all our various sensations we call matter.* Our reference of the sensations to its cause, we call *perception.*

17. The *properties,* and not the *essence* of matter, are the proper objects of philosophical inquiry :—thus, suppose one inquires what is an orange? we answer it is something which is of a round figure, a yellow color, has an agreeable odor, and pleasant taste ;—but we have enumerated only *qualities* or *properties* of the orange; and though we might go on and mention how it grew from a seed, and explain the whole process of vegetation, still we should not have answered the original question, 'what is an orange?'

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12. On what is Natural Philosophy founded?
13. How does the mind learn the properties of matter?
14. Definition of matter. Touch. Sight.
15. Smell and hearing.
16. Perception.
17. What are the proper objects of philosophical inquiry?

if we consider this as referring to its essence. Such inquiries are beyond the limits of our faculties; though in past ages they were vainly pursued by philosophers, who sought rather to perplex men by hypotheses, than to enlighten them by actual discoveries of truth.

18. It is now admitted that mankind must be satisfied with making the best possible use of such knowledge of matter as they can gain by their senses, without attempting to form theories upon subjects beyond their reach, or "to draw on their imagination for facts."

19. The soul within its dark prison can look out upon external things only through those few avenues, the *senses*, which we must suppose reveal to us but a small part of the creation. Were a *sense of discerning spiritual existences* imparted to us, in what a new creation should we seem to exist!

20. But limited as human faculties are in this threshold of existence, they can yet accomplish much by observing, comparing, and experimenting upon such properties of objects as they have the power to perceive. Thus the blind could not, by any expedient, be made to see the forms of letters impressed upon the printed page, and it would be useless labor to attempt to teach them to read in this manner; but by means of *raised characters* which they can learn to distinguish by touch, they may be instructed. Wherein then our Creator has withheld from us light, let us humbly acquiesce in our blindness, while we honor him, and promote our happiness, by making the best possible use of the faculties with which he has endowed us.

21. In the beautiful language of an English writer,* "the character of the true philosopher is to hope all things not impossible, and to believe all things not improbable. He who has seen obscurities which appeared impenetrable, in physical and mathematical science suddenly dispelled, and the most barren and unpromising fields of inquiry converted, as if by inspiration, into rich and inexhaustible springs of knowledge and power, on a simple change of view, or by merely bringing to bear on them some principle which it never occurred before to try, will surely be the very last to acquiesce in any dispiriting prospects of either the present or future destinies of mankind; while, on the other hand, the boundless views of intellectual and moral, as well as material relations, which open to him on all sides in the course of these pursuits, the knowledge of the trivial place he occupies in the scale of creation, and the sense of his own weakness and incapacity to suspend or modify the slightest move-

* Sir John Herschel

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18. What is now admitted with respect to a knowledge of matter?

19. How can the soul gain any knowledge of external things? Is it probable that the senses reveal all which surrounds us?

20. Our limited faculties no excuse for mental inactivity.

21. Character of the true philosopher. Importance of all natural objects to the philosopher.

ment of the vast machinery he sees in action around him, effectually convinces him that *humility of pretension*, no less than confidence of hope, is what best becomes his character. To the natural philosopher, there is no natural object trifling or unimportant. From the least of nature's works he may learn the greatest lessons. The fall of an apple to the ground may raise his thoughts to the laws which govern the revolutions of the planets in their orbits; or the situation of a pebble may afford him evidence of the state of the globe before his species became its denizens. And this is, in fact, one of the great sources of delight which the study of natural science imparts to its votaries. A mind which has once imbibed a taste for scientific inquiry, and has learnt the habit of applying its principles readily to the cases which occur, has within itself an inexhaustible source of pure and exciting contemplations; such a man finds 'tongues in trees, books in the running brooks, sermons in stones, and good in everything.'"

LECTURE II.

OF ABSTRACT SCIENCE.—DEPARTMENTS OF NATURAL PHILOSOPHY.—PROPERTIES OF MATTER.

22. *Natural science* is the knowledge of *things*, of *causes and their effects*; or, in other words, of the *laws of nature*. *Abstract science* is the knowledge of *signs* as in language, or of *numbers*, as in arithmetic or algebra. It is also the study of independent truths which relate to space and extension, as in geometry and all subjects capable of accurate demonstration.

23. Some acquaintance with the *power of language* is necessary towards the comprehension of any science; and the more thorough and extensive is a knowledge of words or the signs used to convey ideas, the more readily can a person comprehend the teachings of others, and the more easily and accurately communicate the results of his own inquiries.

24. The learner in Natural Philosophy should have some acquaintance also with the elementary principles of mathematics, the knowledge of whose truths depends *on reasoning* rather than *observation*. Thus, when we see a triangle marked out before us, and it is demonstrated by a train of geometrical reasoning, that the sum of the three angles is equal to two right angles, we are as perfectly certain of the fact as if it had been proved by actual measurement.

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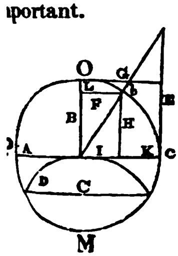
22. Difference between Natural and Abstract science.
23. Importance of understanding the power of language.
24. On what do mathematical truths depend?

25. Upon a few simple truths involving *space* and *numbers* is uilt the noble science of Mathematics. Beginning with these ruths, Euclid, more than two thousand years ago, erected, from materials furnished by his own reason, a system of geometry which succeeding mathematicians have neither been able to overthrow nor improve. Ancient philosophers thought they might, in the same abstract, independent manner, by the mere strength of their own reasoning, establish systems of Natural and Mental Philosophy. But it was soon found that the human mind could never ascertain by any effort of mere reasoning, that sugar would be dissolved by water, or marble remain unchanged in the same liquid.

26. The progress of the physical sciences was long obstructed by the blindness of the learned to the true mode of scientific investigations. As soon as philosophers began to understand that he only way of learning the laws of nature is to *observe* natural henomena, and, consequently, began to substitute *inquiry* for hypothesis, discoveries were made and principles established.

27. The science of Natural Philosophy is intimately connected th Mathematical Science; and though we may not, in teaching former, make use of mathematical demonstrations, they are the indation on which depend many of the principles of philosophy.

28. The particular branch of geometry called *trigonometry*,* ables the astronomer to use the earth as a base wherewith to asure the magnitude and distances of the sun and planets: it o enables the navigator on the broad ocean, to ascertain by obrvations of the stars his exact position on the earth's surface. determining the heights of mountains and buildings, and in the erations of the surveyor, the science of trigonometry is equally portant.



29. The annexed diagram shows some of the most important geometrical lines and figures. A *c* is the *diameter* of the *circle* O P M; B, a *radius;* C, a *chord;* D, an *arc;* E, a *tangent;* F, a *secant;* G, a *co-tangent;* H, the *sine* of the arc *a b*; I, the *co sine;* K, the *versed sine;* L, the sine of the arc *b* O. The *sine* of an arc or angle is the perpendicular line drawn from the extremity of an arc O *b*, to the diameter of a circle, as H; I is called the *co-sine*, and K the *versed sine;* L is the sine of complemental arc O *b*.

* From the Greek *trigonon* and *metreo*, signifying to measure *triangles*.

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25. On what did Euclid erect his system of geometry?
26. What obstructed the progress of the physical sciences?
27 Connection of Natural Philosophy with Mathematical Science.
28. Uses of trigonometry.
29 Explain the diagram of geometrical lines and figures.

DIVISIONS OF NATURAL PHILOSOPHY.

30. Natural philosophy is divided into MECHANICS or the mechanical properties of matter and the doctrine of equilibrium and motion as respects *solids;* HYDROSTATICS, relating to the equilibrium and motion of *liquids;* PNEUMATICS, or the effect of forces on air and other *gaseous* fluids; ACOUSTICS, or the science of sound; OPTICS, the science which treats of *light and vision.* To these may be added ELECTRO-MAGNETISM and ASTRONOMY.

MECHANICS.

Essential Properties of Matter.

31. The *two essential properties of matter,* are *extension* and *impenetrability.* All matter of which we have any knowledge exists in *masses* called *bodies.*

32. All material substances have *extension* in *length, breadth* and *thickness,* and these constitute the *dimensions* of a body. Even the air which encompasses the globe is a body and has its dimensions;—a river has its length, breadth and depth. The terms *height, depth,* and *thickness,* all mean the same thing although we apply them differently. When we measure from the base upward, we call this dimension, *height;* thus we say the height of a mountain; when we measure from the surface downward, we say *depth,* as of a river;—*thickness* is not applied to water or gasses, but to solids only, as the thickness of ice, of a stratum of rock, &c. *Width* is also synonymous with breadth.

33. The *extension of a body,* or that space which it occupies, is called its *volume,* and the quantity of matter which it contains, its *mass.* A portion of space which is destitute of matter, is called a *vacuum.*

34. The limits of extension are called *figure* or *shape.* The productions of nature are seldom bounded by straight lines, thus animals and vegetables exhibit beautiful curves, and a graceful irregularity. Rocks and mountains have no determinate forms, and the masses which compose them are also irregular. Crystals present regular geometrical figures, each mineral substance pos-

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30. What are the departments into which Natural Philosophy may be divided.
31. Which are the two essential properties of matter?
32. What constitute the dimensions of a body?
33. Volume, mass, vacuum.
34. *Figure, or shape.*

sessing, its own peculiar form of crystal, as each species of plant has its own form of leaf.

35. By *impenetrability* is meant that property which a body has of occupying a certain space, and of *excluding all other matter from the space it occupies;* otherwise, any space might contain an indefinite quantity of matter, and bodies instead of resisting, would pass through each other, which is contrary to our daily experience.

36. Air and water are bodies; we can no more penetrate the particles which compose these substances than those of a board or a piece of iron. In moving the hand through the air, we do not penetrate its particles, but they make way on each side. If the hand is plunged into a vessel filled with water, a quantity, equal in bulk to the hand, will flow out. The particles which compose air and water move freely, and are therefore easily separated from one another.

37. In solid substances, such as wood and metals, the particles are less easily separated; but a nail may be driven into the one, and a rivet drilled through the other; in common language they are said to be *penetrated* by the nail or rivet; but, in these cases, there is also a displacing of the particles which are crowded more closely, in order to make way for the harder bodies forcibly introduced.

38. This property in bodies may be considered as the mainspring of all mechanical science. It is impenetrability which gives the force necessary to motion, affording to the sails of vessels, the oars of boats, the wheels of mills, and various kinds of machinery, a resistance in air and water, without which human invention would be unavailing.

We can form no notion of matter that has not *extension*, or dimensions, or that does not occupy space, in other words that is not *impenetrable;* therefore we consider extension and impenetrability as *essential* properties of bodies.

Properties of Matter not considered Essential.

39. *Divisibility* was long classed among the essential properties of matter, but in the present state of science, we cannot consider it as such. By divisibility is meant, that we can never divide a substance into parts so minute, that it may not be again

35. Impenetrability.
36. Impenetrabilty of air and water.
37. Does a nail or rivet penetrate the particles of wood or iron?
38. Importance of impenetrability in mechanics.
39. Is divisibility an essential property of matter? Examples of extreme *divisibility of matter.*

12. This science is founded on *observation and experiment*; that is, it admits no principle which is not the result of careful and attentive observation, and which may not be tested by actual experiment.

13. *Matter* is the subject of the science, and *mind* the instrument by which its operations are carried on. By means of the senses, which are, themselves, subject to the will of the soul or mind, the latter becomes acquainted with objects external to itself.

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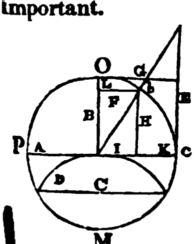
23. Importance of understanding the power of language.
24. *On what do mathematical truths depend?*

25. Upon a few simple truths involving *space* and *numbers* is built the noble science of Mathematics. Beginning with these truths, Euclid, more than two thousand years ago, erected, from materials furnished by his own reason, a system of geometry which succeeding mathematicians have neither been able to overthrow nor improve. Ancient philosophers thought they might, in the same abstract, independent manner, by the mere strength of their own reasoning, establish systems of Natural and Mental Philosophy. But it was soon found that the human mind could never ascertain by any effort of mere reasoning, that sugar would be dissolved by water, or marble remain unchanged in the same liquid.

26. The progress of the physical sciences was long obstructed by the blindness of the learned to the true mode of scientific investigations. As soon as philosophers began to understand that the only way of learning the laws of nature is to *observe* natural phenomena, and, consequently, began to substitute *inquiry* for hypothesis, discoveries were made and principles established.

27. The science of Natural Philosophy is intimately connected with Mathematical Science; and though we may not, in teaching the former, make use of mathematical demonstrations, they are the foundation on which depend many of the principles of philosophy.

28. The particular branch of geometry called *trigonometry*,* enables the astronomer to use the earth as a base wherewith to measure the magnitude and distances of the sun and planets: it also enables the navigator on the broad ocean, to ascertain by observations of the stars his exact position on the earth's surface. In determining the heights of mountains and buildings, and in the operations of the surveyor, the science of trigonometry is equally important.



29. The annexed diagram shows some of the most important geometrical lines and figures. A *c* is the *diameter* of the *circle* O P M; B, a *radius;* C, a *chord;* D, an *arc;* E, a *tangent;* F, a *secant;* G, a *co-tangent;* H, the *sine* of the arc *a b;* I, the *co sine;* K, the *versed sine;* L, the sine of the arc *b* O. The *sine* of an arc or angle is the perpendicular line drawn from the extremity of an arc O *b*, to the diameter of a circle, as H; I is called the *co-sine*, and K the *versed sine;* L is the sine of complemental arc O *b*.

* From the Greek *trigonon* and *metreo*, signifying to measure *triangles*.

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25. On what did Euclid erect his system of geometry?
26. What obstructed the progress of the physical sciences?
27. Connection of Natural Philosophy with Mathematical Science.
28. Uses of trigonometry.
29. Explain the diagram of geometrical lines and figures.

DIVISIONS OF NATURAL PHILOSOPHY.

30. Natural philosophy is divided into MECHANICS or the mechanical properties of matter and the doctrine of equilibrium and motion as respects *solids;* HYDROSTATICS, relating to the equilibrium and motion of *liquids;* PNEUMATICS, or the effect of forces on *air* and other *gaseous* fluids; ACOUSTICS, or the science of *sound;* OPTICS, the science which treats of *light and vision.* To these may be added ELECTRO-MAGNETISM and ASTRONOMY.

MECHANICS.

Essential Properties of Matter.

31. The *two essential properties of matter*, are *extension* and *impenetrability.* All matter of which we have any knowledge, exists in *masses* called *bodies.*

32. All material substances have *extension* in *length, breadth* and *thickness*, and these constitute the *dimensions* of a body. Even the air which encompasses the globe is a body and has its dimensions;—a river has its length, breadth and depth. The terms *height, depth,* and *thickness,* all mean the same thing although we apply them differently. When we measure from the base upward, we call this dimension, *height;* thus we say the height of a mountain; when we measure from the surface downward, we say *depth,* as of a river;—*thickness* is not applied to water or gasses, but to solids only, as the thickness of ice, of a stratum of rock, &c. *Width* is also synonymous with breadth.

33. The *extension of a body,* or that space which it occupies, is called its *volume,* and the quantity of matter which it contains, its *mass.* A portion of space which is destitute of matter, is called a *vacuum.*

34. The limits of extension are called *figure* or *shape.* The productions of nature are seldom bounded by straight lines, thus animals and vegetables exhibit beautiful curves, and a graceful irregularity. Rocks and mountains have no determinate forms, and the masses which compose them are also irregular. Crystals present regular geometrical figures, each mineral substance pos-

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30. What are the departments into which Natural Philosophy may be divided.
31. Which are the two essential properties of matter?
32. What constitute the dimensions of a body?
33. Volume, mass, vacuum.
34. Figure, or shape.

sessing, its own peculiar form of crystal, as each species of plant has its own form of leaf.

35. By *impenetrability* is meant that property which a body has of occupying a certain space, and of *excluding all other matter from the space it occupies;* otherwise, any space might contain an indefinite quantity of matter, and bodies instead of resisting, would pass through each other, which is contrary to our daily experience.

36. Air and water are bodies; we can no more penetrate the particles which compose these substances than those of a board or a piece of iron. In moving the hand through the air, we do not penetrate its particles, but they make way on each side. If the hand is plunged into a vessel filled with water, a quantity, equal in bulk to the hand, will flow out. The particles which compose air and water move freely, and are therefore easily separated from one another.

37. In solid substances, such as wood and metals, the particles are less easily separated; but a nail may be driven into the one, and a rivet drilled through the other; in common language they are said to be *penetrated* by the nail or rivet; but, in these cases, there is also a displacing of the particles which are crowded more closely, in order to make way for the harder bodies forcibly introduced.

38. This property in bodies may be considered as the mainspring of all mechanical science. It is impenetrability which gives the force necessary to motion, affording to the sails of vessels, the oars of boats, the wheels of mills, and various kinds of machinery, a resistance in air and water, without which human invention would be unavailing.

We can form no notion of matter that has not *extension*, or dimensions, or that does not occupy space, in other words that is not *impenetrable;* therefore we consider extension and impenetrability as *essential* properties of bodies.

Properties of Matter not considered Essential.

39. *Divisibility* was long classed among the essential properties of matter, but in the present state of science, we cannot consider it as such. By divisibility is meant, that we can never divide a substance into parts so minute, that it may not be again

35. Impenetrability.
36. Impenetrabilty of air and water.
37. Does a nail or rivet penetrate the particles of wood or iron?
38. Importance of impenetrability in mechanics.
39. Is divisibility an essential property of matter? Examples of extreme divisibility of matter.

divided; thus, it has been asserted, that *matter* is *infinitely divisible.* In proof of this opinion, it is said that any particle of matter must have an upper and under side; every whole must have two halves, four quarters, &c.* The extreme minuteness of division of which some substances are capable, is considered a proof of this infinite divisibility of matter. We know that a single odoriferous flower will perfume a large apartment; the odor which passing from it, comes in contact with our organs of smell, is, in fact, particles of the flower itself; but though it may continue for many days to diffuse perfume, its substance does not seem at all lessened by the loss of these particles. A small bottle of perfume will, for years, continue to diffuse odor, without any apparent diminution of its substance. The dust obtained by pounding a crystal, when examined with a microscope, presents the same form and angles which distinguished the mass; and this dust is capable of farther subdivision with instruments sufficiently delicate.

40. The microscope reveals, in the fine powder upon the outside of a fig, *animalculæ,* which, though, in reality, so small that many thousands might stand upon the point of a fine needle, appear like droves of pigs, each, with limbs and the various organs necessary to carry on the functions of animal life.

Suppose that an instrument should be constructed, (and the supposition is not absurd,) which, in its magnifying powers, should exceed any microscope now known, as much as that does the unassisted powers of the eye; what new wonders might be revealed to us and what new proofs given of the divisibility of matter! But examples showing that matter is divisible to a wonderful extent, do not prove that there may not be ultimate particles which cannot be divided.

* Although it may be impossible, by means of mechanical subdivision, as pounding, grinding, &c. to arrive at the ultimate atoms of bodies, yet *chemical decomposition* can effect what mechanical means cannot.

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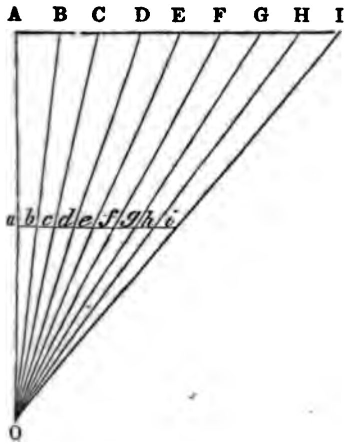
40. Discoveries of the great divisibility of matter by means of the microscope.

Fig. 1.



41. Geometry teaches that *space* is infinitely divisible. In this science it is taken for granted, that a line, however small, may be divided. It may be demonstrated that the line *a i* is capable of being divided into any number of equal parts. Draw a line A I, parallel to *a i*, of any length, and at any distance you please, and divide it into as many equal parts, A B, B C, &c. as there are to be divisions in the smaller given line, say eight. Now, through the extremities A *a*, and I *i* draw the straight lines A *a* O and I *i* O, till they meet in the point O; and from O, draw to the points of division B, C, D, E, &c. the straight lines O B, O C, &c. which shall likewise divide the smaller line into eight equal parts. This operation, *mathematically* speaking, may be performed, however small the given line *a i*, and however great the number of parts into which we may propose to divide it; though, in executing geometrical figures the lines may touch each other and lose their distinctness, as may be seen near the point O, because lines which we draw have some breadth. Thus, *physically*, this proposition is not true, though, *mathematically* speaking, there is no line, however small, which may not be again divided.

42. But space is not matter, therefore if its infinite divisibility were demonstrated, this would not prove the infinite divisibility of matter. Though Philosophy has not been able to determine this subject, Chemistry, a sister science, comes to our aid, and informs us that, by *the analysis of bodies, she has discovered that they are composed of atoms,** *or particles which cannot be again divided.*†

43. *Porosity* is a property which is found to exist in an inverse proportion to density. The *pores* or interstices of sponge are filled with air. Put the sponge in water, and air will escape

* The word *atoms* is from the Greek, and signifies that which cannot be further cut or divided.

† Although in late works on Natural Philosophy, *divisibility* has been insisted on as an essential property of matter, the doctrine of atoms, or indivisible particles is by no means modern. Sir Isaac Newton says, "all things considered, it seems probable that God in the beginning, formed matter in solid, massy, hard, impenetrable, moveable particles, of such sizes and figures, and with such other properties, and in such proportion to space as most conduced to the end for which he formed them."

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41. Space proved by geometry to be infinitely divisible.
42. If it were proved that space is infinitely divisible, would this argument apply to matter? How has the existence of ultimate atoms been proved?
43. What is meant by porosity, and in what substances does it exist?

in little bubbles and give place to water. Wood and even metals are porous, though the pores are less visible than in sponge and light bread. Oil spilled upon an oaken or pine floor is absorbed by pores in the wood; by the application of substances, such as soap or lye, which unite with the oil and change its nature, its effects are destroyed. Metals formed into thin globes and filled with liquid, on being subjected to powerful pressure have exhibited their outer surface covered with moisture exuded through the pores. The diamond, the hardest of all known substances, admits the passage of light. As matter is impenetrable, we must consider this, and all other cases of transparency as owing to the porosity of the substance.

44. *Density* is closeness of texture. Bodies are heavy in pro portion as they are dense. In two bodies of equal bulk, that is most dense which weighs most. Sponge is less dense than wood, and wood is less dense than iron. The metals vary in their degrees of density; platina is more dense than gold, and gold is more dense than silver. Any body can be made more dense by bringing its particles into a more compact state, by hammering, pressure, &c.

45. *Compressibility* is owing to the porosity of matter. All known substances are capable of being made to occupy less space, by forcing the particles which compose them into closer contiguity.. The more dense a substance is, the less it is compressible. *Hardness* and *softness* are terms which, in common language, signify the same properties as density and compressibility.

46. *Expansion* is that property of matter whereby the particles which compose a body are divided to a great distance, and thus occupy more space than in their ordinary state.

47. *Elasticity* is that property by which a body after being compressed, returns to its original form on the removal of the compressing force. Elastic bodies, as ivory, marble and steel, when thrown against any hard substance, rebound; but non-elastic bodies, as wet-clay, dough, putty, &c., adhere to the substances on which they fall, and do not return to their former shape.

Gravity and *Inertia* are properties of matter which are intimately connected with the laws of motion.

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44. Why are some bodies heavier than others? What property is the opposite of porosity? Density of metals.
45. Compressibility.
46. Expansion.
47. Elasticity. Gravity and Inertia.

LECTURE III.

INERTIA.—ATTRACTION AND REPULSION.—DIFFERENT KINDS OF ATTRACTION.

Inertia.

48. *Inertia* is a property of matter by which it resists any change of state, whether of rest or motion. Matter is inactive, it has neither the power to move, nor to stop its own motion. The term inertia was introduced into Philosophy by those who maintained that all bodies have a propensity to rest. They considered matter as somewhat resembling indolent persons, who prefer rest to exertion, ascribing to bodies a dislike to motion, similar to that which sluggards have for labor. This opinion was founded on a false view of the nature of matter which requires as much force to put it in a state of rest as of motion.

49. Matter does not move itself; a stone, for example, never raises itself from the ground, nor, without some external force, moves in any direction. A stone thrown from the hand, after moving for a time, at length falls to the earth, and its motion ceases. It may be asked, "does not this prove that the stone has a tendency to rest, rather than motion?" We answer, that force is equally necessary in the one case as in the other, although the exertion of it is not equally apparent in both cases. We see the force which impels the stone, but cannot see that which stops its motion.

50. The *resistance of air* impedes the motion of bodies; and besides this, there is, constantly in operation, a powerful force, called the *attraction of gravitation*, which tends to bring to the earth all substances within its sphere of action.

51. A top whirled from the hand spins swiftly at first, but gradually moves more slowly, until its motion ceases, and it rests upon the floor. The *friction*, or rubbing against the floor, the *resistance of the air*, and the *attraction of gravitation*, are the united

48. Define inertia. Has matter any power to move, or to stop its own motion? What was the origin of the term inertia?

49. Force as necessary to stop motion, as to produce it.

50. What forces tend to destroy upward motion?

51. What three forces tend to bring a whirling top to a state of rest?

forces which stop the motion of the top; or, by their continued operation, at length overcome the impulse at first given by the force of the hand.

52. The inertia of a body is proportional to its quantity of matter or weight.

Attraction and Repulsion.

53. There are, in nature, two opposite powers, *attraction* and *repulsion;* the former tends to bring the particles of matter together, the latter to drive them asunder. These powers, by the Creator and Governor of the universe, are made to balance each other; were it otherwise, disorder and ruin would prevail in the material world.

54. Should attraction reign uncontrolled, the particles which compose bodies would rush together into close contact. According to the suggestion of some philosophers, our globe and all that it contains might be compressed to the size of an apple. It is a familiar fact that nearly two thousand gallons of steam may be condensed to one gallon of water.

55. Repulsion, operating without any check from attraction, would destroy the solidity of all bodies on the earth, and even the earth itself; which, in that case, would exist only in the form of the most rarefied gas. The burning of a log of wood shows a solid body passing off in vapor, since all that remains solid is a small quantity of ashes bearing but a very small proportion to the size of the wood.

56. The great agent in repulsion, is the principle of heat, called *caloric*, the consideration of which belongs to Chemistry.

Cohesive Attraction.

57. The attraction of *cohesion* is the force which keeps the particles of matter together, forming distinct bodies. It acts only at *insensible distances.* The table, the iron stove and looking glass are composed of very small particles of matter, held together by the power of cohesion. On attempting to separate a solid body, we perceive that it is held together by a power which

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52. To what is inertia proportional?
53. What two opposite powers in nature?
54. Effects of uncontrolled attraction.
55. Of repulsion.
56. The great agent in repulsion.
57. Attraction of cohesion. What is necessary towards cohesive attraction? What would be the effect if this power were to cease?

requires more or less resistance to overcome. This is cohesive, sometimes called *adhesive* attraction.

If two flat peices of lead, with smooth surfaces, be brought together, they will be held in contact by a powerful force. Two plates of glass when placed together will cohere so strongly as not to be easily separated.

58. Liquids are less influenced than solids by cohesive attraction. In drops of dew suspended from the leaves of plants we see the operation of this power, both in the globular form which the particles of moisture assume, and in their remaining attached to the leaf. If small globules of mercury are placed upon a plate of glass or other smooth substance, they will move towards each other and unite. In order that this should take place, the globules of mercury must be brought within the sphere of their mutual attraction. Liquids, in common language, are said to be thick or thin according as their cohesive attraction is more or less powerful; but *dense* and *rare* are more scientific terms, thus, quicksilver is said to be a dense, and air a rare fluid.

59. It is by the attraction of cohesion that liquids arrange themselves around a common center in globular forms; thus dew, which is moisture existing in the atmosphere in very minute particles, may be seen in the morning suspended in drops from the leaves of plants, and adhering to the blades of grass. Drops of water thrown upon an oiled surface, the globular form assumed by liquid mercury, hail-stones, &c., are illustrations of this power. On a large scale, the sun and planets may be referred to, and their globular form affords a strong argument to prove that they were originally in such a state of fluidity as allowed their particles to arrange themselves according to the laws of cohesion in liquids.

Capillary Attraction.

60. *Capillary** *attraction* is that power by which liquids rise through minute tubes. This is probably only a form of cohesive

* The term capillary, is from the Latin *capillus*, a hair.

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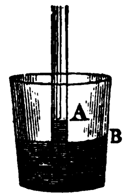
58. Cohesion in liquids.
59. Globular form of liquids. Examples.
60. What is capillary attraction?

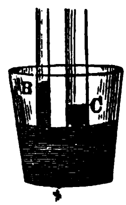
attraction. The fluid appears to creep along ı attracted by the contiguous particles of the tub(

Fig. 2.



61. The figure represents a glass partly filled water, and having a small tube placed within it fluid in the latter is seen at A, above the level : It is also seen that the fluid at B is concave, or hi at the sides than in the center; this is in consequ of the attraction of the particles of matter which pose the ring of the glass contiguous to the upper face of the fluid.

Fig. 3.



62. *The larger the bore of the tube, the le the attractive power.* If two tubes of differen ameter be immersed in a vessel of colored wat(will be found that the liquid will rise as much hi in the smaller tube, B, as the diameter of its bo less than that of the larger tube, C.

63. The power of capillary attraction is manif(in a variety of common occurrences. If one en(piece of bread be dipped in water, the liquid will make its way until the whole is moistened. wicks of candles and lamps supply the flame by means of ta or oil, which ascends through the capillary tubes of the co Rocks are sometimes split by driving into a crevice a wed dry wood, which, being exposed to rains, swells by the absor of water, with sufficient force to rend asunder the hardest sto

64. It might appear that the mercury in the small tube thermometer rises by means of capillary attraction. But th not the fact, as in order that this kind of attraction should place, *the tube must be composed of a substance which attract particles of the liquid with greater force than they attract other;* thus, particles of mercury cannot be attracted by tho glass; while mercury rises in small tubes of tin or silver, and in glass tubes coated with oil.

65. Capillary attraction is only another form of cohesion, w in modern science is included under the general term, *mole(* attraction, the attraction of *molecules,* atoms or minute parti

66. *Chemical attraction* or *affinity,* is that force which u dissimilar particles, and cannot, like cohesion, be overcome b mechanical force, such as pounding, grinding, &c.

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61. 1st experiment.
62. 2nd experiment.
63. Familiar examples of capillary attraction.
64. Does capillary attraction affect the mercury in the tube of the mometer?
65. Molecular attraction.
66. Chemical attraction.

67. *Magnetic attraction* is the power possessed by the *load-stone* or magnetic iron, of drawing towards it portions of iron or steel. This power causes the magnetic needle to point directly towards the poles of the earth.

68. *Electrical attraction* is a property which certain bodies possess, when excited by friction, of attracting other bodies.

LECTURE IV.

GRAVITY.

69. All terrestial bodies fall toward the earth when not supported. Before the 17th century, mankind had never thought of inquiring why bodies thus fell. It is related that the fall of an apple from a tree, under which the young Sir Isaac Newton was sitting, was the occasion which led him to philosophize on the subject of falling bodies. "Why," he reasoned, "did this apple take a downward, rather than an upward direction, or why did it move at all? There can be no motion without force; the tree did not push the apple down; where then is the force which caused its descent?" In considering the subject farther, he reflected that the earth, everywhere, attracted bodies towards its surface, in the deep valleys and upon the high mountains. This power of attraction he called *gravitation*.

70. It was something to have been the first to reflect and reason upon the cause of a fact, which had escaped the inquiry of all preceding philosophers. But Newton stopped not here;—he beheld the moon pursuing her regular course around the earth, and was led to inquire whether she was attracted towards the earth; and if so, why she too did not fall upon its surface. The result of his reasoning was the discovery that gravitation is not confined to the earth, but that its power pervades the solar system, causing not only the motion of the moon around the earth, but the revolutions of the earth and other planets around the sun. There are reasons also for believing that the same principle of gravitation operates in the most distant regions of space, binding

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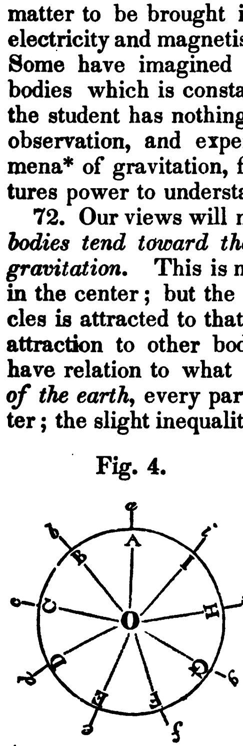
67. Magnetic attraction.
68. Electrical attraction.
69. Discovery of gravitation.
70 Its extent.

together other solar systems, and perhaps causing them and our own system to revolve around some common center.

71. *The attraction of gravitation or gravity is that force by which distant bodies tend towards each other.* It differs from cohesion and chemical attraction in not requiring the particles of matter to be brought in contact, but acts on remote bodies like electricity and magnetism. The cause of gravitation is not known. Some have imagined that a subtle, invisible fluid, issues from bodies which is constantly tending to draw them together. But the student has nothing to do with speculations unsupported by observation, and experience; his object is to learn the phenomena* of gravitation, for these the Almighty has given his creatures power to understand.

72. Our views will now be directed to *terrestrial* gravity. *All bodies tend toward the center of the earth by the attraction of gravitation.* This is not owing to any peculiar power of attraction in the center; but the earth being a globe, each of its own particles is attracted to that point which thus becomes the center of attraction to other bodies. The terms *upward* and *downward* have relation to what is *farthest from*, or *nearest to the surface of the earth*, every part of which is equally distant from the center; the slight inequality of mountains and valleys, being, in comparison with the whole circumference, of no perceptible importance.

Fig. 4.



Let the figure represent the globe of the earth, and suppose bodies could fall freely from any point on its surface through its diameter; a ball dropped from either of the points, A, B, C, &c. would be attracted towards O at the center, and move in a straight line to that point where it would rest. The lines *a* A, *b* B, &c. are all vertical, and point downward, or to the center. Thus, we perceive that all bodies will fall perpendicularly to the surface of the earth, and, if not impeded, would penetrate to the center at O.

* *Phenomenon* in common language signifies some extraordinary appearance; in science it means merely a *change* of *appearance*. *Phenomena* is the plural of phenomenon.

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71. Definition of gravity. Cause of gravitation unknown.
72. Terrestrial gravity. Why are bodies attracted to the center of the earth? To what do the terms upward and downward relate?

Fig. 5.

A B

73. The real figure of the earth was not understood by the ancients. They supposed it to be a flat mass of matter, whose surface only was habitable, and that A B were the extreme impassable points. When the opinion was first advanced that the earth was a sphere, and that there were inhabitants on the opposite side of its surface, it was considered as a heresy, and treated with great severity, both by civil and ecclesiastical rulers. "If there are people," said they, "who live on the other side of the globe, they must have their heads downwards and their feet upwards; and how could they hold fast to the under side of this ball? It is an insult to religion and common sense to pretend such a thing." Some attempted to explain the matter by asserting that the antipodes* he'd to the surface of the earth, as insects crawl on the under, as well as the upper side of a small globe. But they did not reflect that the insect adheres thus by means of its claws. Navigators, in sailing around the globe, have neither found people with claws, nor any who considered themselves as living on the under side of the globe; all, alike, have the broad arch of the heavens above, and the firm earth beneath them. Besides, let us recollect that in twelve hours, by the earth's rotation on its axis, we shall be where our antipodes now are. The figure represents the sphere of the earth, with two figures standing at opposite points. Were each at the same moment to drop an apple, the two apples would fall towards the earth, and supposing they were able to pass freely through it, would penetrate to the center, and being attracted equally, on all sides, would there remain at rest.

Fig. 6.

74. *Weight is the force with which a body is attracted to the earth, and this force is in proportion to the quantity of matter.* The quantity of matter does not depend on the size of the body. A piece of lead weighs heavier than a block of wood of the same size, because the lead has more density than the wood, or, within the same bulk, it contains more particles of matter.

75. As the force of the earth's attraction is in proportion to the quantity of matter, if this quantity were doubled, bodies near its surface would *weigh* twice as much as they now do; or if the earth contained only half its present quantity of matter, the weight of bodies would be lessened in the same proportion.

* *Antipodes* is from the Greek *anti* against, *podes* feet.

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73. Opinion of the ancients respecting the figure of the earth.
74. What is weight? Does the quantity of matter in a body depend on its size?
75. In what case would bodies weigh twice as much as they now do?

Fig. 7.

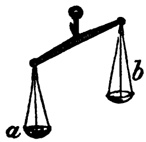

Fig. 8.

76. *Weight* is measured by its mech fects, such as bending a spring, or turn ance; or, it is measured by the force th to hold a body back to keep it from fallin

77. The balance consists of a horizontal bar, so that its two arms, with the scales attached, are equilibrium. A merchant wishing to weigh a po puts into the scale *a*, a leaden pound weight, wh gravity, causes the scale to descend. As the ar weighed, is put into the other scale *b*, *a* begins t when the mass equals that of the leaden pound the two scales are again in equilibrium, as at Fig

78. The bulk of a pound of tea is great that of the leaden pound weight; hence, the *specific gravity* of the latter, is greate that of the former.

79. We have said that all terrestrial bodies are attracte the earth. It may be objected that this is not the fact with smoke, steam, and especially the gas* used to inflate balloon not only raises the balloon, but carries the aeronaut into th regions of the atmosphere. But these and similar phen are, in reality, instances of the effects of gravitation, for cending bodies are driven upward solely by the force of dium through which they pass; since the particles of sm vapor, or the balloon, cannot advance upward without dis portions of the atmosphere equal to their own bulk. A bl wood when plunged into a vessel of water rises and float the surface, because the specific gravity of wood is less th of water, and the heaviest body being most strongly att forces the lighter one upward. Lead, on being thrown into sel containing mercury, will swim on the surface, and, if down, it re-ascends; but gold in the same situation, will sink. specific gravity of gold is greater, and that of lead less than of mercury.

80. Air being lighter than the solid and liquid bodies on earth keeps its place above them; but air has weight, being jected to the universal law of gravitation. The air near the face of the earth is more dense than in the upper regions. sons who ascend high mountains or rise to great heights in loons find a difficulty in breathing on account of the rarity of air. The increased density in the lower strata of the atmosph

* Hydrogen.

76. How is weight measured?
77. The balance.
78. Specific gravity.
79. Why do smoke, steam, &c. ascend? **Wood and lead made to s**
80. *Has air* weight? Unequal density of the air—its cause.

is owing to the pressure of the upper portions; as the lower fleeces in a pile of wool are more compact, or dense, than those which are not subjected to the same degree of pressure.

81. *Pressure*, as well as the motion of falling bodies, proves that attraction is universal. When a stone is held in the hand, the pressure is in proportion to its quantity of matter. It is evident that a force is in operation tending to draw the stone downwards.

82. As the force of gravitation is proportioned to the quantity of matter, it follows that *all bodies would fall with equal velocity, if they met with no resistance.* A feather and a leaden bullet, dropped from a given height together, would reach the ground at the same instant, were it not for the *resistance of the air*, which the lighter body cannot so readily overcome. The medium through which bodies fall, impedes their descent, in an inverse* proportion to the specific gravity of these bodies. By means of an apparatus called an air-pump, we are able to exhaust, or pump out the air from vessels placed over it.

83. *The attraction of gravitation is reciprocal;* that is, every particle of matter attracts every other, as much as it is attracted by it. If the larger of two bodies have four times the number of particles as the smaller, it would exert four times as much attractive force; or, cause the smaller body to move with four times as great velocity as it would, if the masses of the bodies were equal. It is owing to the immense difference between the mass of the earth and that of any one body on its surface, that the attractive influence of bodies falling towards the earth, produces an effect too slight for observation. The earth, though held in its annual motion by the attraction of the sun, a body one million of times greater than itself, has no perceptible effect on the sun's position. The Moon is made to revolve round the earth, its superior in size; yet the attraction of the moon is sensibly felt upon the earth, in the production of tides.

84. The *resistance of the air is always in proportion to the surface of bodies;* a lump of gold that would, in falling, seem little impeded by this resistance, may be hammered into thin sheets called *gold leaf*, so that the same particles of matter shall cover a surface many millions of times greater; and the increased resistance of the air will be in proportion to the increase of surface.

* By *inverse* is meant contrary to, or the opposite of, from the Latin *in*, and *verto*, to turn.

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81. Pressure.

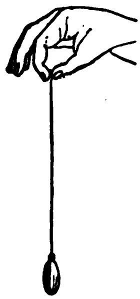
82. Do all bodies fall with equal velocity? Why would not a feather fall to the ground from any given height, in the same time that a bullet would fall from the same height?

83. Attraction of gravitation reciprocal.

84. Resistance of the air, in proportion to what?

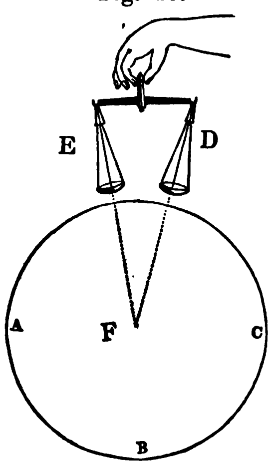
85. *Bodies in falling*, unless drawn aside by some other force, always *move in lines perpendicular to the surface of the earth.* If a small piece of lead be suspended by a cord, the latter will hang in a *vertical* line. This is called a *plumb* or *plummet* line (from the Latin, *plumbum*, lead;) it is of great use to mechanics in finding the true perpendicular, for the walls of buildings, &c. The floors of a house should be in a horizontal plane or level, the walls and partitions perpendicular.

Fig. 9.



86. A plummet line suspended from a high mountain, *is drawn from the perpendicular toward the side of the mountain;* this is owing to the attraction of the mountain, which, though small in comparison to the whole earth, is capable of interfering with its attraction, because gravity diminishes as the squares of the distance increase; in this case, the attraction of the smaller body, on account of its nearness, overcomes that of the larger, but more distant body.

Fig. 10.



87. *No two bodies can fall to the earth in parallel lines*, for as they are all attracted to the center, the lines, if prolonged, must continue to approach, until they meet in that point.

Thus, the two sides of a pair of scales do not hang exactly parallel to each other; A B C represents the earth's sphere, and E D a balance suspended over it. The lines D F and E F, which meet in the centre of the sphere, are not parallel, for parallel lines, if produced to any length, never meet. The convergence* in common scales is too slight to be perceptible to our senses; but in the figure, the beam of the scales is represented as extending through several degrees of the earth's circle.

88. *Where there is no attraction there can be no weight.* If there

* *Converging* lines are such as incline toward each other, and if sufficiently extended would at length meet.

85. Plumb-line.
86. Why will a plummet-line suspended from a high mountain be drawn from the perpendicular?
87. Can two bodies fall to the earth in parallel lines?
88. In what case would there be no weight?

were but one body in the universe, it is evident that this would be attracted by nothing, and remain at rest; and, though it were of the magnitude of the sun, together with that of all the planets, it would not press in any direction sufficiently to counterbalance the weight of a feather.

89. *The force of gravity is greatest at the surface of the earth, from whence it decreases both upward and downward.* In ascending from the earth's surface, the force of gravity decreases as the *squares* of the *distance from the center* increase. This proposition asserts, that as the distance from the center of the earth increases, the force of gravity diminishes; and that the degree of diminution is not simply proportional to the increase of distance, so as to be one-half at double the distance, and one-third at three times the distance, but it is proportioned to the square of the distance, so that at twice the distance it is only one-fourth as great, at three times the distance only one-ninth, &c.

90. The square of any number is that number multiplied by itself; thus the square of 2 is 4, the square of 4 is 16, the square of 16 is 256, &c. A body, which at the surface of the earth, viz. 4000 miles from the center* would weigh one pound, if carried to twice this height from the center, namely, 8000 miles, would weigh one-fourth of a pound; if carried 12000 miles from the center, or *three* times the distance of the surface of the earth from the center, its weight would be diminished to one-ninth of a pound. The moon is about sixty times as far from the center of the earth as the distance from that center to the surface, (that is, 240,000 miles); therefore, as the square of 60 is 3600, the attraction of the earth at the moon is 3600 times less than at the earth's surface; so that a body which here weighs one pound, would, at the distance of the moon, weigh only the three thousand and six hundredth part of a pound.

91. *The force of gravity from the earth's surface downwards, decreases simply as the distance;* so that at 2000 miles, or half way from the surface to the center, a body weighing one pound at the surface would weigh but half a pound; at 3000 miles, or three-fourths the distance from the surface to the center, it would weigh but one quarter of a pound; and at the center it would have no weight.

* Or half the diameter of the earth.

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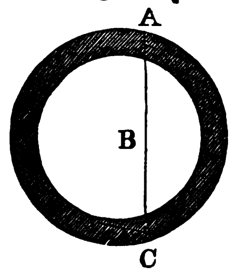
89. Where is the force of gravity greatest? State the law of gravity at different distances above the earth's surface.

90. What is meant by the square of any number? By what method of calculation can we determine what would be the weight of any body at the moon, its weight at the earth's surface being ascertained?

91. How does the force of gravity from the earth's surface downwards decrease?

92. *A body situated within a hollow sphere would remain at rest in any part of the void.* Suppose the earth to be a hollow sphere, surounded by a crust A. C.; a ball. B, introduced into the empty space would remain at rest; for while the nearer portions of the crust, on the right of the line A C, would attract the ball more than the remoter portions, on the left of the line A C, the greater quantity of matter on the latter side would be an exact counterpoise.

Fig. 11.



93. A body carried from Philadelphia to the north pole would gain in weight; if carried to the equator it would lose in weight. This is owing to the spheroidal form of the earth, or its being flattened at the poles, which are somewhat nearer the center of the earth than is the equator; the poles being nearer the center of attraction, the force of gravity is greater there than at the equator.

LECTURE V.

CENTER OF GRAVITY.

94. *The center of gravity is that point in a body, about which, the body acted upon only by gravity, will balance itself.* Therefore, if a body be supported by the center of gravity, it will rest in any position, and, whatever supports that point bears the weight of the whole mass. A cane may be poised upon the finger, its center of gravity being supported.

95. Though in any mass of matter, every atom has its separate gravity and inertia, and the weight and inertia are, in reality, diffused through the whole, yet, as there is one point which, when supported, balances the whole, and, when not supported leaves the whole to fall, the *weight* of the body may be considered as centered at that point.

96. In a body of a *regular figure*, and *composed of a substance of uniform density, the centre of gravity is the same as the center*

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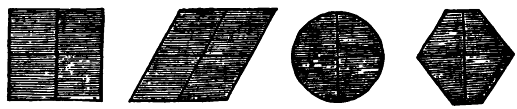
92. Suppose a body situated in a hollow sphere.
93. Difference in the weight of bodies at the equator and the poles.
94. What is the center of gravity?
95. What is the center of weight?
96. Is the center of magnitude always at the same point as the center of *gravity?*

of magnitude, as in a cube of wood, or ball of lead; this center of the cube or ball is also the center of gravity.

In the following figures, the lines intersect each other in the center of the figure, and supposing each to be of a uniform density, this center is also the point around which the quantities of matter are equal on all sides, and therefore exactly balance each other.

Fig. 12.



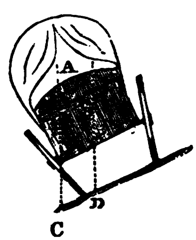
97. *If a body be suspended from a fixed point, the center of gravity will always be in a vertical line beneath the point of suspension.*

In the case of a body of equal thickness but of an irregular form, as a piece of board, to find the center of gravity, suspend it by one corner, and from the same corner let fall a plumb-line, and mark its direction on the board. Now suspend the board from any other point, marking the direction of the plumb-line as before, the point of intersection of the two lines is the center of gravity.

98. A vertical line drawn through the center of gravity, is called the *line of direction*. If the line of direction fall within the base of the body, it will stand; but if it fall without the base, the body will fall.

99. A carriage moves securely over a level road, because the center of gravity falls between the wheels, and is supported. Where one side of the road is much higher than the other, there is always danger that a carriage will be overturned; and this danger is increased, in proportion as the height of the carriage or of the load is increased.

Fig. 13.



Suppose A to be the center of gravity, the line of direction (or the line which is drawn through the center of gravity perpendicular to the earth) is then towards C, which, not falling within the wheels, is not supported by them, of course the load must be upset. But supposing part of the load to be taken off, or that instead of some light loading, such as wool or hay, the cart were loaded with iron or stone, the center of gravity would then be lower, as at B, and the line of direction, B D, being thus within the wheels, the body would be supported.

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97. How is the center of gravity found?

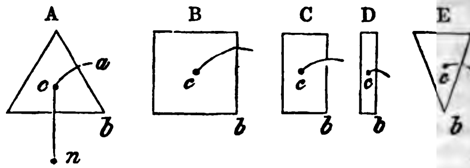
98. What is meant by the line of direction?

99. Why does a carriage move most securely over a level road? Effect of height in increasing the danger of upsetting a load.

100. The form of bodies is of great importance in giving firmness of support; for, while some cannot be moved withou ing the center of gravity, others can be set in motion by the sl est force. *The broader the base, and the nearer the line of di tion to the center of it, the more firmly does a body stand ; the narrower the base of a body, and the nearer the line of di tion to the side of it, the more easily it is overthrown.*

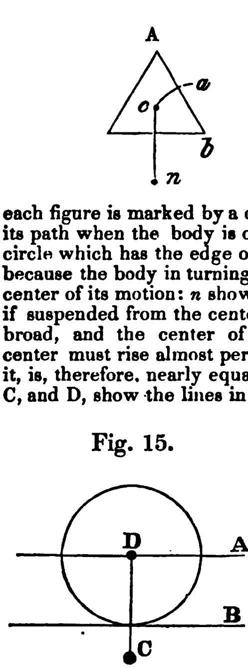
101. In the following figures, the two particulars, *base* and *height* combined in a series of proportions. The place of the center of gravity

Fig. 14.



each figure is marked by a dot, and the curved line proceeding from it show its path when the body is overturned. This curved line is a portion of circle which has the edge or extremity of the base *b*, in Fig. A, as a cent because the body in turning, must rest upon such extremity, or corner as th center of its motion: *n* shows the *line of direction*, or where a plummet line if suspended from the center of gravity, would fall. In Fig. A, the base broad, and the center of gravity is low; before the body can fall, the center must rise almost perpendicularly; and the resistance in overturning it, is, therefore, nearly equal to the weight of the whole body. Figures B, C, and D, show the lines in which the body must fall, to be more and more inclined as their bases become narrower; consequently the bodies stand less firmly in proportion. B represents a square house; C a tall, narrow house; and D a very high chimney. At Fig. E, the center of gravity being over a base which is a mere point, the body is in a tottering position, and at the least degree of inclination would fall. When a round body is rolled on a horizontal plane, the center of gravity is not raised, but moves in a straight line parallel to the surface of the plane on which it rolls; the center of gravity, therefore, is always directly over the center of motion. B is the plane on which the ball moves, A the line in which the center of gravity moves, and C a plumb-line; D is the center of gravity, directly above the center of motion. A ball on a horizontal plane will rest with equal firmness in any position, and the center of gravity will describe a horizontal line over that of motion, in whatever direction the body is moved. If the plane is inclined downward, the ball will be

Fig. 15.



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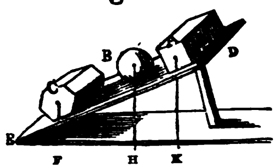
100. Importance of the form of bodies in giving them firmness. Law of gravitation in respect to the form of bodies.

101 Various forms of bodies in relation to base and height.

set in motion, the center of gravity being in advance of the centre of motion, or that point on which the ball rested.

Fig. 16.



102. *Spherical bodies* are easily rolled down an inclined plane, because their base is but a point, and the smallest force is sufficient to remove the *line of direction out of its base.* We perceive by the lines of direction, F H K, that the body A will slide down the plane D E, while B and C will roll down the same.

103. A ball or cylinder rolls downwards by the force of gravitation, because its center of gravity in approaching the earth, is continually urging forward the center of motion. The difficulty of rolling heavy bodies up an ascent, arises from the fact that the center of gravity is behind that of motion, and continually tending to impede its progress.

104. The center of gravity in any body which is left free to assume its natural position, is such, that a line drawn from this center to the point where the body rests, will be the shortest that can be drawn from the center to any part of its surface. Thus an oval body would not stand in the position represented in the figure, but would turn until the shorter line, A C, became perpendicular to the supporting surface instead of the longer line, A B. *The center of gravity, when bodies are not supported, always seeks the lowest situation.*

Fig. 17.

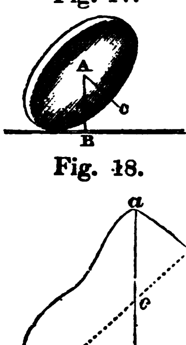
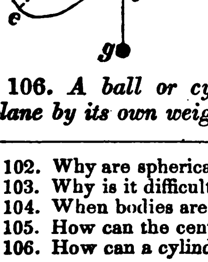


Fig. 18.



105. In the case of an irregular solid, let us suppose the figure to represent a piece of board suspended from the point *a*; let a plumb line, *a g*, also be suspended from *a*, and mark the direction of the string on the surface of the board. Then suspend the board from any other point, as *d*, and also the plumb line from the same point, and mark its direction; the point *c*, where the two lines cross each other, is the center of gravity.

106. *A ball or cylinder may be made to roll up an inclined plane by its own weight.* Let A B, represent a cylinder of light

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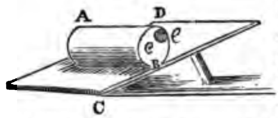
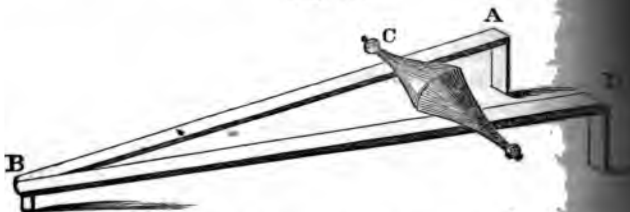
102. Why are spherical bodies easily moved?
103. Why is it difficult to roll heavy bodies up an ascent?
104. When bodies are left free, where will the center of gravity rest?
105. How can the center of gravity be found in an irregular solid?
106. How can a cylinder be made to roll up an inclined plane?

Fig. 19.



wood, having its center of g
c, and placed on the inclined
D ; it is evident, that as its li
rection from the center of gra
out of its base, it would roll dow
if at e, a ball of lead be inser
the cylinder, it will then roll u
till the lead gets as near the surface of the plane as possib
therefore when the cylinder is ascending, the lead is desce

Fig. 20.



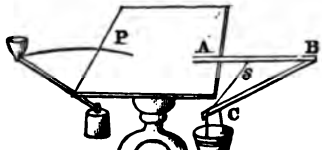
107. Another experiment of a similar kind serves, also, to show th
of the unequal distribution of weig
different parts of a moving body. A d
cone, C, (Fig. 20) united at the base,
ascend the inclined plane, made by
ing a jointed rule, A B, and raising i
the open end, A D. But though the
ascends, its *center*, which is the ce
of gravity, really *sinks* lower and lo
between the sides of the rule, as it
vances to the open end.

Fig. 21.

108. The figure of a horse, with
the hind feet supported on a pedes
represents a toy in which the weigh
a ball below the horse, by bringing dow
the center of gravity, causes a vibrato
motion when either the rider or horse i
touched.

109. Let A B represent a stick restin
on the edge of a table; if left to itsel
this would fall, bacause its center of
gravity is beyond the table; but the
pail, C, being suspended by a string,
s, from the stick, A B, instead of
pulling it down, supports it by

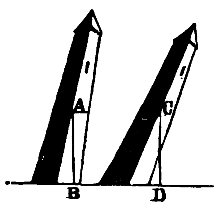
Fig. 22.



107. Ex. of the double cone.
108. Scientific toy.
109. How can a pail of water supported by a stick lying loosely table.

means of another stick, C B, which rests against a niche in the end of A B and presses against the string at the point from which the pail is suspended. Now the stick, A B, cannot fall without lifting the weight of the pail, or raising the center of gravity. On the opposite side of the table at P, is a common tobacco pipe, which may be made to sustain any weight that is not sufficient to destroy the cohesion of its particles. An umbrella or walking cane, hanging on the edge of a table is supported on a like principle.

Fig. 23.

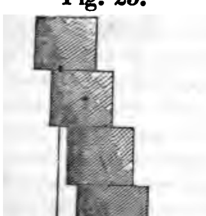


110. A building, though leaning considerably from the perpendicular, will not fall, so long as the center of gravity is supported. A column or steeple might, without endangering its stability, have an inclination as great as that in the figure, where A B represents the line of direction ; but this would not be the case, where C D falls without the base.

111. Tall spires and turrets, after a lapse of time, are often seen to lean from the perpendicular ; but if they are properly constructed, they may long endure, even in this state. In Pisa in Italy, where are many ancient and remarkable buildings, is a celebrated *leaning tower*, which was built in the twelfth century. It is of marble, 168 feet in height, and leans sixteen feet from the perpendicular. Some suppose, that this beautiful tower was designedly built in this manner, to excite emotions of wonder in the spectator, beholding its lofty top thus bending over its base. Others believe it to have gradually sunk to its present position. An illustration of the leaning tower may be made by piling blocks of wood upon each other, as represented in the figure. When the third block is added, the centre of gravity is within the base, as shown by the line of direction A, and the column, though leaning, is supported. But when the fourth block is added, the line of direction B, being without the base, the column falls.

Fig. 24.

Fig. 25.



112. When two bodies of equal weight are connected by a rod, the center of gravity will be in the middle of the rod, and a

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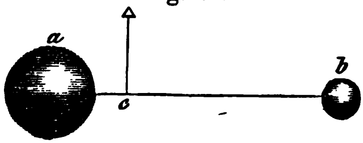
110. Building leaning from the perpendicular.
111. Tower of Pisa. How illustrated.
112. *Center of gravity in two bodies* connected.

Fig. 26.



string fastened to this point will hold the whole in equilibrium. But, if the bodies are of unequal weight, the center of gravity is nearest the greater weight. That is, if *a* be a weight of three pounds, and *b* a weight of one pound, a string fastened to the point *c*, three times nearer to the center of the large weight, than to that of the small one, will hold the two bodies in equilibrium.

113. *A person can carry two pails of water, at the same time, with nearly as much ease as he could carry one*, because the two pails balance each other, and the feet more naturally sustain the center of gravity than when this is thrown on one side by the weight of a single pail.

114. The center of gravity is also the *center of inertia.*

115. If a person lift a rod of uniform density by the middle, he overcomes the inertia of the whole mass. If he lift it by a part nearer to one end, the shorter, and consequently the lighter part, will rise first, because the center of inertia is in the other.

116. We perceive the intimate connection between the principles of Natural Philosophy and the mechanic arts, since not even a chimney can be constructed without constant reference to the plumb line. The moderns, in their structures, study elegance and comfort rather than durability; the walls of modern brick and stone buildings, being so slight, that if they vary, in the least, from the perpendicular, they are in danger of falling. They afford in this respect, a great contrast to the massy piles of antiquity.

117. *Force applied to the center of inertia or gravity, will produce an effect which cannot be produced by much greater force, acting on other portions of a body.* A blow with a hammer upon a large rocking stone, if falling upon a part distant from the center of inertia, (or gravity,) might destroy the cohesion of particles, so as to break off a portion of the rock without moving the whole mass; while the same force, so applied as to affect the center of inertia, would set the rock in motion. If the motion were to begin on a horizontal plane, it might stop with overturning the rock; but if, on the downward side of a hill, the rock would continue to move to the foot of the declivity, and as much further on the level ground, as the impulse received from the original blow and from

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113. A person carrying two pails of water.
114. Center of Inertia.
115. Inertia overcome.
116. Mechanic arts connected with Philosophy.
117. To what point in a body should efforts to remove a heavy body be applied? In what case might a portion of a rock be broken off, without moving the whole mass?

velocity would carry it. The *resistance of friction* would at length overcome the *inertia of motion.*

118. *The motions of animals, of man in particular, illustrate the foregoing laws with respect to the center of gravity.* We have found, that a body with a narrow base is less easily supported than one with a broad base, and that the greater height requires the greater base; but man walks erect, firmly supporting his tall figure on a very narrow base, and in a variety of attitudes. This supporting base is the space occupied by, and included between the feet.

Persons who turn the toes outward in walking, have then the advantage of a broader base, which adds, not only grace, but firmness to their gait. We may, in various attitudes of human beings, perceive these two qualities, grace and firmness, intimately connected; by this we mean, that those positions in which the center of gravity is best supported, are the most graceful. The best rule for fine attitudes is, to keep the center of gravity of the body well over the base. This center in the human being is between the hips; by setting the feet in parallel lines, and close together, the figure is not firmly supported, and considerable muscular effort is necessary to keep the body erect.

119. In sitting down, or in rising from a seat, much of the grace of motion depends on the manner in which the center of gravity is lowered or raised. Some persons drop into a chair as if they were lumps of inert matter, influenced only by gravitation; whereas the muscles of the lower limbs should be so exercised that the center of gravity may descend slowly, and gracefully. In rising from a seat, the body must be inclined forward, to bring the center of gravity over the feet or base; and, in this position, the muscular force of the hips and lower limbs is sufficient to effect the object.

120. It is said that a man having agreed to give ten guineas for the privilege of attempting to possess himself of a purse of twenty guineas, by picking it up when laid before him on the floor, lost his money. The conditions were that he should stand with his heels against a perpendicular wall, and in this position, should pick up the purse. Under these circumstances, the forward inclination of the head and arms would throw the center of gravity beyond the base, and the man must fall; in order to reach the floor with his hands, it was necessary to throw one foot backward, which the wall prevented.

121. In walking, the center of gravity is alternately over the right and the left foot; if one foot be injured so that it sustains the weight of the body with difficulty, the lame person advances only with the well foot, using the other merely to rest upon, while the well foot moves the weight. A man carrying a burden on his back, leans forward; if the weight be in his arms, he leans backward; if on his head, he walks erect. If the load be on one shoulder, he leans to the other side. When a man stumbles with one foot, he extends the opposite arm. In ascending a hill, he bends forward, and in descending he leans backward. In all these cases the object is, to support the center of gravity, and to bring the center of direction within the base, that is, the feet.

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118. Laws of gravity illustrated by the motions of animals.

119. Rising up, and sitting down.

120. Why could not a man pick up a purse, and at the same time stand with his heels against a wall?

121. Change of the centre of gravity in walking, &c.

122. The young child does not learn to stand, much less to walk, till long practice in position has taught him how to support his weight, and the muscular efforts necessary to move it. The kitten, and other quadrupeds, sustained by broad bases, have no need to learn the art of standing. But we seldom see these animals raising the two feet on one side, at the same time.

123. The *vegetable kingdom*, no less than the animal, is subjected to the laws of gravitation. Tall trees have their roots wide spreading, in proportion to their height, thus furnishing a broad and firm basis of support. Their line of direction, also, is as unerring as in any works of art; the pine and fir grow as perpendicularly as the builder can construct a column. Who will say that a divine master builder does not rear these stately pillars of nature's temple! Upon the hill side as upon the level plain, with undeviating regularity do they rise toward heaven, as if to do homage to their Creator.

LECTURE VI.

MOTION AND FORCE.—LAWS OF MOTION.

124. All bodies are either in a state of rest or motion. They have no tendency to the one state more than the other; but require force not only to put them in motion when at rest, but to cause them to stop when once in motion.

125. *Motion* may be defined a change of place.

126. *Absolute motion* is a change of place with respect to any fixed point; a person walking or riding is in absolute motion.

127. *Relative motion* is a change of place in a body in motion, with respect to another body, also in motion. Suppose a person standing on that part of the deck of a steamboat farthest from the shore, should, at the moment of the boat's starting off, begin to run towards the shore, and move, at the same rate at which the boat was moving, to the other end of the deck; his position with respect to the objects on shore, would be, exactly, what it was when the boat started, though *changed in relation to the boat.*

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122. Why does a young child find it more difficult to support its weigh than young quadrupeds?

123. Have the laws of gravity any influence in the vegetable kingdom.

124. Have bodies any more tendency to a state of rest than of motion.

125. What is motion?

126. Absolute motion.

127. Relative motion.

128. *Apparent motion* is caused by the real motion of the spectator. In moving swiftly along, in a carriage or boat, the objects around us appear to be in motion ; those we have past, seeming to recede, and those before us, to approach. The motion of the earth on its axis, causes the *apparent* motion of the sun ; thus we say "the sun rises or the sun sets," as the passenger on board a vessel says "the shore is receding from us."

129. We have remarked upon that property of matter called inertia, or a passiveness, with regard, either to motion or rest ; as there is nothing within, which can put inert matter in motion, this effect must be produced by the agency of some external power ; this power is called *force.*

130. Force, may be *muscular*, as in the action of men and animals; or *mechanical*, as in the action of wind, water, steam, and gravity.

131. *Velocity*, is a term applied to bodies in motion. A bird darting through the air, moves with great velocity ; a tortoise moves with little velocity ; that is, the *time* in which the bird and the tortoise would pass over a given *space*, would be different.

132. The velocity of motion is estimated *by the time spent in moving over a certain space*, or, by *the space moved over in a certain time. The less the time, and the greater the space moved over, the greater is the velocity ; but the greater the time, and the less the space moved over, the less is the velocity.*

133. To ascertain the degree of velocity, *divide the space by the time* ;—suppose a person travels 30 miles in 6 hours ; to know his velocity, divide 30 by 6, the answer is 5. That is, he traveled at the rate of 5 miles an hour ; thus *velocity equals space divided* by time.

134. To ascertain the *time* in which motion is performed, *divide the space by the velocity* ;—if a man has traveled 30 miles, at the rate of 5 miles an hour, (as 30 divided by 5 is 6,) in 6 hours, he has performed the journey.

135. To ascertain the *space* moved over, *multiply the time into the velocity* ;—thus, 6 hours representing the time, is multiplied by 5, which stands for the velocity, or rate of motion, and the answer is 30, which stands for space, or distance traveled. Where any two of the three circumstances, *velocity, time* and *space* are given, the third may be ascertained.

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128. Apparent motion.
129. What is the power called which produces motion?
130. What are the different kinds of force?
131. What is velocity?
132. How is velocity estimated?
133. How can you ascertain the degree of velocity?
134. How can you ascertain the time in which motion is performed?
135. How the space moved over?

136. The rules above given, apply only to cases of *uniform* motion, that is ; when the body passes over *equal spaces* in *equal portions of time*, as the index of a clock.

EXAMPLES.

1. If a bird fly 6,000 feet in 5 hours, what is its velocity per ninute ? *Ans.* 20 feet.

2. A carriage passes over 28 miles in 7 hours, what is its velocity per hour ? *Ans.* 4 miles.

3. If a boat is propelled by the oars 4 miles an hour, and by the current 2 miles an hour, how long will it be in passing over 24 miles ? *Ans.* 4 hours.

4. A western emigrant travels 5 miles an hour, how far will he go in 4 days, traveling 10 hours each day ? *Ans.* 200 miles.

137. *Accelerated motion* is when the space described in equal portions of time continually increase, as in the case of bodies falling by the force of gravity.

138. *Retarded motion* is when the spaces described in equal portions of time continually decrease ; the motion of a body thrown upward is continually retarded by the earth's attraction.

139. The *momentum* of a body is its moving force, or *quantity of motion*, and this is in proportion to its weight and velocity.

140. A cannon ball, thrown against a person with the hand, might have only momentum enough to bruise the flesh ; while the same ball shot, at the same distance, from a cannon, would pass through the body. The *weight*, in both cases is the same, but the *difference in the velocity* causes the difference in the momentum.

141. A block of wood, floating slowly against a person's limb suspended from a dock, would scarcely be felt, while a loaded vessel, moving at the same rate, would crush it. Here the *velocity is the same*, but the *weight different*.

The boy who throws a ball, or shoots a marble, knows that its force, or momentum, is in proportion to its velocity ; that the same ball will strike twice as *hard* if it move twice as fast, or ten times as hard if it move ten times as fast. Let the word *momentum* be substituted for *hard*, and *velocity* for *fast*, and we have the fact expressed in scientific terms.

142. The momentum of bodies is one of the most important

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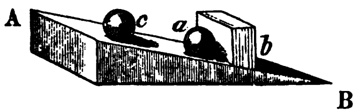
136. In what cases do these rules apply? Examples.
137. Accelerated motion.
138. Retarded motion.
139. Momentum.
140. Momentum caused by velocity.
141. Momentum of weight. Terms substituted for momentum and velocity.
142. How do machines derive their power?

principles in mechanics. Machines derive their powers *by opposing matter to motion.*

Fig. 27.



143. *Force* is that cause which moves, or tends to move, a body, or to change its motion. If the ball *a*, be *placed gently* against the block *b*, the force will not be sufficient to move it; but let the same ball be placed at *c*, and *rolled down the inclined plane* A B, the momentum will be so great as to overcome the resistance of the block. In the former case, *b* would only have to resist the *weight* of the ball *a*; in the latter, it has to resist the *weight, multiplied into its velocity. The momentum of a body is proportioned to the product of its quantity of matter, and its velocity.*

EXAMPLES.

144. A weighs 50 pounds, and moves at the rate of 20 feet in a second; B weighs 100 pounds and moves at the rate of ten feet in a second; what are their momenta?* 50 multiplied by 20 is 1000; 100 multiplied by 10 is 1000; therefore their momenta are equal, being both represented by 1000. In this example, we see that a smaller body moving with a greater velocity, has a momentum equal to that of a larger body moving with less velocity.

145. A weighs 15 pounds, and moves with a velocity of 5 feet in a second, and B weighs 12 pounds and moves with a velocity of 6 feet in a second; what are their momenta? the momentum

of A, $15\times5=75$

of B, $12\times6=72$†

146. The momentum of bodies may be calculated by the simple rule of multiplication. A ball, A, weighing 2 pounds, and moving with a velocity of 6 miles an hour, will strike with a momentum which may be represented by the product of 2 multiplied by 6, viz., 12; and a ball, B, weighing 6 pounds, and moving with the velocity of 8 miles an hour, has a momentum equal to

* Momenta is the plural of momentum.

† $\times$ is the sign of multiplication, $=$ of equality, thus: $12\times6=72$, signifies that 12, multiplied by 6, equals 72.

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143. Definition of force. To what is the momentum of a body proportioned?

144. Example of equal momenta and unequal weight.

145. Example 2nd. of equal momenta and unequal weight.

146. Rules for calculating momentum. Examples.

these two numbers multiplied together, viz. 48. In comparing the momenta of the two balls, we have only to divide the greater by the smaller number; thus 48 divided by 12 gives 4, so that the momentum of B is four times that of A, or, in other words, B moves with four times the force of A.

Suppose a mass of snow weighing 2700 pounds, descends the Green Mountains, with a velocity of 15 feet per second; with what momentum will it fall. *Ans.* 40,500 pounds.

If a ball of 20 pounds' weight, fall with a velocity of 5 feet per second, and one of 25 pounds' weight, with a velocity of 4 feet per second, what are their comparative momenta? *Ans.* Equal;

for $20 \times 5 = 100$,
$25 \times 4 = 100$,

147. When two bodies of equal weight meet, the shock is the same whether the motion be shared between them, or be wholly in one:—but where their weight is different, the shock is greater to the smaller body. If one person run against another, who is standing, both receive a shock. If both be running at the same rate in opposite directions, the shock is doubled. In some cases, as in swift skating, when the velocity is very great, the momentum has been sufficient to destroy the lives of those who have thus met.

"When two ships meet at sea, although each may be sailing at a moderate rate, the destruction is often as complete to both, as if, with double velocity, they had struck on a rock. Many melancholy instances of this kind are on record. In the darkness of night, a large ship has met one smaller and weaker, and in the lapse of a few seconds, have followed the shock of the encounter, the scream of the surprised victims, and the horrible silence when the waves had closed over them and their vessel forever."*

OF THE LAWS OF MOTION.

148. There are three important principles, or *laws of motion*, which are of extensive application in mechanical philosophy.

First law of motion: *a body continues always in a state of rest, or of uniform motion in a right line, till compelled to change that state by some external force.*

149. This law of motion is the necessary result of the *inertia* of matter, which resists any change of state, whether of motion or rest. The resistance of the air, friction, and gravitation, are forces which tend to stop motion. On account of the various obstacles which exist at the surface of the earth, we see here no instances of perpetual motion; but the heavenly bodies in their con-

* Arnott's Elements of Physics.

147. Double shock caused by the meeting of bodies.
148. First law of motion.
149. What does the first law of motion result from? Perpetual motion *of the heavenly* bodies.

tinued and undeviating revolutions, show the tendency of matter to continue in motion, when meeting with no impediments.

150. It requires more force to produce motion in a body at rest, than to keep the same body in motion; as a horse may be obliged to use strong efforts to start a load, which he can draw easily, after the resistance of rest has been overcome. In large bodies, motion should be applied gradually, or it may affect only a part of the mass, and thus destroy its cohesion. If a team with a heavy load be suddenly started forward, there is danger of breaking the harness. The child soon learns, that when he has a load upon his little cart, he must pull with a gentle and steady force, or his string will be in danger of breaking.

151. The effect of inertia in bodies *in motion*, is no less striking than with respect to those at rest. If a ship sailing with only a moderate velocity, suddenly stop, the passengers within, to whom the motion had not been perceptible, experience a shock, and the movable furniture is thrown forward. Should the earth be suddenly stopped in its diurnal motion, everything on its surface would be thrown eastward, or in the direction towards which the earth was revolving.

152. SECOND LAW OF MOTION: *the motion of a body is in the direction of the force which produces it, and is proportional to that force.*

153. That *motion is in the direction of the force impressed*, is understood by the boy who throws a stone upwards, to bring down an apple* from a tree; or who strikes his ball with the wish of driving it to any particular point. Another boy turns the same ball out of its intended course, by giving it with a side-blow an oblique direction. A wind blowing to one point of the compass, impels bodies in the same direction. The sportsman levels his gun, and the shot impelled by the expansive force of the gunpowder, moves exactly in the direction he intends.

154. *Motion is proportional to the force which produces it.* To throw a ball weighing two pounds, a distance of ten feet, requires twice as much force, as to throw a ball weighing one pound, the same distance; or, a ball of one pound weight, moves twice as fast as a ball of two pounds weight, if both are impelled by the same force. Again, if two balls of equal weight are impelled, the

* The apple being detached from the tree by the momentum of the stone, is brought to the ground by a new power, viz., gravitation.

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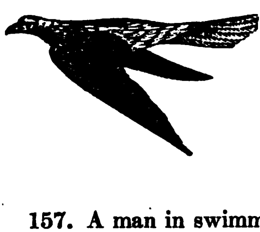
150. Resistance of rest.
151. The resistance of motion.
152. Second law of motion.
153. Motion in the direction of the force impressed.
154. Motion proportioned to the force which produced it.

one with a force twice as great as the other, the quantity of motion of the one, will be twice as great as that of the other. A man by exerting his strength, might with a rope, draw a small skiff to shore very quickly; a loaded barge would, with the same force, move slowly, and a large ship with scarcely a perceptible motion.

155. THIRD LAW OF MOTION: *to every action of one body upon another, there is an equal and contrary reaction;* or, when a body communicates motion to another, it loses of its own momentum as much as it imparts.

156. If a man in one boat, pull at a rope attached to another, his own boat will be moved by the force which he uses; if the two boats be of equal size and load, they will both move at the same rate, and meet half way from the places from which they started. If a man in a small boat, should attempt to pull towards him a large ship, his own boat would move with a velocity, greater in proportion, as its weight is less than that of the ship; but if in a large ship he should draw towards him a little boat, the ship itself would be reacted upon, and move, although not enough to be perceptible to the senses. This may be the better understood, by supposing that *if the resistance of the ship were one thousand times greater than that of the boat, a thousand men in as many boats,* all pulling together in one direction, would cause the ship to meet them half way. A boatman pushes off his boat by pressing with his oar against the land, the force reacting in the opposite direction; by a continued succession of back strokes, and the reaction of the water upon the boat, it is moved forward. The bird flies upward, by striking the air with its wings in a downward direction; the air reacting upon his body, raises him at each stroke. In flying through the air in a horizontal direction, the stroke with his wings would be backward, like the strokes of a boatman with his oar.

Fig. 28.



157. A man in swimming, by striking the water downward and backward with his hands, is borne upward and forward by the reaction of the water. The cripple setting his crutches upon the ground, receives a reacting force in his arms, which thus perform part of the labor of walking.

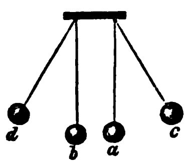
158. The third law of motion may be illustrated by the percus-

155. Third law of motion. The force which produced it.
156. Examples illustrating the third law of motion.
157. Further examples—swimming—walking on crutches.
158. How may the third law of motion be illustrated? Percussion. *Elastic bodies.*

sion of *elastic* and *non-elastic* bodies. By *percussion*, is meant the *collision*, or striking together of bodies. *Elastic* bodies, are those which, after compression, return to their former state. If bodies have the power of restoring themselves immediately after compression, or possess a force equal to any compressing power, they are said to be *perfectly elastic*. *Air* is an example of this; a bladder filled with air, after being compressed, will immediately expand to its former bulk. *Solid bodies which will retain no permanent bend*, are highly elastic, as marble, steel, and glass. A good steel sword may be bent until its ends meet, and yet return to its former state on being released from the force by which it was bent. Bad steel is not thus elastic, but will break in bending. A pane of glass may be bent, but will instantly spring back. Indian rubber is highly elastic, though not perfectly so, for after being frequently stretched, it will appear to have lost something of its power to resume its former state. A ball of wool, cotton, or sponge when compressed, exhibits the property of elasticity.

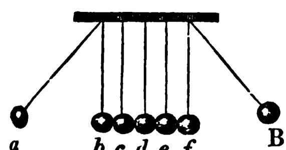
159. *When two perfectly elastic bodies, of equal weight and velocity, strike against each other, the striking body communicates the whole of its motion to the other, and then remains at rest.*

Fig. 29.



Suppose two ivory balls *a b*, of equal weight, be suspended by threads; let *a* be drawn aside to *c*, and then let fall against *b*, it will drive it to *d*, or a distance equal to that through which *a* had fallen, while the latter, having imparted all its motion, remains at rest, at *a*.

Fig. 30.



160. Or, suppose a number of ivory balls of equal weight to be suspended by threads, and the ball *a* be drawn aside and then suffered to fall against *b*, the latter will communicate its motion to *c* and then stop; *c* will in like manner communicate its motion to *d*, and thus each ball will successively transmit its motion to the next, and remain at rest, while the last ball *f*, will move off to B with the original velocity of *a*.

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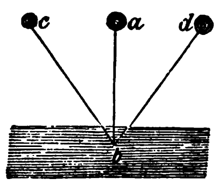
159. *Two elastic balls striking against* each other. Example.
160. Motion *communicated to* several elastic balls.

161. The elasticity of balls of ivory and marble may seem doubtful, since they cannot be compressed with the hand, like an indian rubber or cotton ball. But an ivory letter-folder, or riding-stick, is manifestly elastic, since, when bent, it springs back as soon as the force is withdrawn. That both ivory and marble do yield by collision, is proved by a very simple experiment. If an ivory ball fall upon a marble slab, owing to the elasticity of both bodies, it will rebound nearly to the height from which it fell, and there will be no visible mark of any compression of either body; but let the marble slab be wet, and from the fact that a *circular surface, of some extent*, is found dried by the blow, it will be seen that both bodies had yielded at the point of contact. Billiard balls retain their perfect form, and even their polish, for a long time, although they are, in reality, indented at every stroke; but, from their great elasticity, the compressed parts instantly spring back. Sealing wax retains the impression of the seal because it has no elasticity, or power to spring back after the resistance is removed. Figures can be stamped on soft clay, and unleavened dough, for the same reason. In raised dough, owing to its pores being filled with an elastic fluid,* there is much elasticity.

162. *If an elastic body fall upon an immovable obstacle, it will rebound with a force equal to the stroke, and in a contrary direction;* thus exemplifying the third law of motion, that action and reaction are equal, and in contrary directions.

163. If a ball of ivory, or any other elastic substance, be dropped perpendicularly upon a marble slab, or other hard, immovable body, it will rebound in the same straight line in which it fell; but if thrown obliquely, it will not rebound in the same line by which it first moved, but as obliquely, on the opposite side. Suppose an elastic ball *a*, to fall upon a hard substance *b*; if it fall perpendicularly, or in the line *a b*, it will rebound in the same perpendicular, or in the line *b a*; but if it fall in the direction *c b*, it will rebound in the line *b d*. Now *c b* is the line of *incidence*.† and *d b* is the line of *reflection*,‡ and the more oblique or slanting the former line is, the more so will be the latter. The perpen-

Fig. 31.



* Carbonic acid gas.

† *Incidence*, from the Latin *incidens*, falling upon.

‡ *Reflection*, from the Latin *re* and *flecto*, signifying to throw back.

161. Ivory and marble proved to be elastic.

162. An elastic body falling against an immovable object.

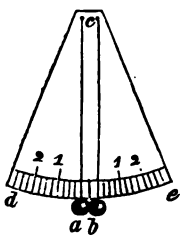
163. Elastic balls falling perpendicularly. Angles of incidence and reflection equal.

dicular line *a b** divides the angle made by the lines of incidence and reflection into two parts or angles, and these angles are equal, from whence it follows, that the *angle of incidence is always equal to the angle of reflection.* The boy who throws his ball upon the pavement, may chance to see a glass window broken by its rebound, if he disregard this law of reflection. Sound and light are reflected in the same manner as solid elastic bodies.

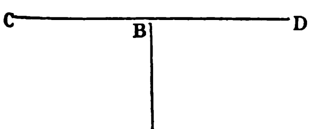
Fig. 32.

164. *Non-elastic* bodies, are those which are destitute of the elastic spring. When one non-elastic body strikes another, the bodies do not rebound as in the case of elastic bodies. Lead, dough, moist clay, &c., are non-elastic.

Fig. 33.



165. Suppose *a* and *b*, to be two *non-elastic balls*, suspended at *c* by threads of equal length, so that they may be in contact when at rest; and let *d e* be a graduated arc over which the balls may move; then if the ball *b*, be moved a certain number of degrees towards *e*, and let fall so that it will strike the ball *a*, *it will communicate to the latter, half its momentum, and both balls will move towards d*, through a number of degrees proportioned to their common velocity; that is, half as far as the ball *b* would have moved if it had met with no obstruction; but as the two balls, containing twice the quantity of matter, are now moved by the same force which impelled *b*, it follows that the velocity is diminished by one half.



* It may be well here to explain, that though, in general, we mean by a perpendicular line, one that falls in a right line toward the center of the earth; in geometry, any line which makes right angles with another line is said to be a perpendicular line; and in this sense, the line A B, falling upon C D, or the wall of an apartment, is a perpendicular line, although, commonly speaking, a line in that direction would be horizontal.

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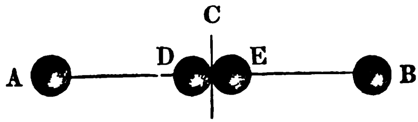
164. Non-elastic bodies.
165. A non-elastic body in motion falling against one at rest.

166. *If two non-elastic bodies of equal weight and velocity strike against each other, the momenta of both will be destroyed.* Suppose that the two bodies, A B, have equal weight and velocity, and of course equal momenta; moving in opposite directions they meet at C, by which stroke the momenta of both balls are destroyed, and they remain at rest, as seen at D and E.

Fig. 34.



If a non-elastic body strike upon an immovable obstacle, it will lose all its motion. For example, let a ball of lead, or of soft clay fall upon the floor, and it will stop without any rebound.

LECTURE VII.

COMPOUND MOTION.—COMPOSITION AND RESOLUTION OF FORCES.

167. A STONE thrown by the hand, or a ball shot from a gun, is generally considered as an example of *simple motion,* though even here, the force of gravity is in operation. Strictly speaking, there is no case of simple motion, since, in the absolute motion of all terrestrial bodies, is combined that of the earth, in its diurnal and annual revolutions.

168. *Compound motion is that which is produced by several forces acting in different, but not in opposite directions.*

169. *If forces be equal, and their directions exactly opposite to each other,* the body acted upon will not move at all.

170. *When two forces* (not in direct opposition) *act upon a body at the same time, as it cannot move two ways at once, it holds a middle course between the directions of the separate forces.* This course is called the *resulting direction, or resultant,* because it results from the *composition* or *union* of the forces.

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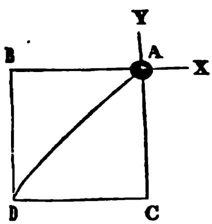
166. Meeting of two non-elastic bodies in motion.
167. Simple motion,
168. Compound motion.
169. Equal and opposite forces.
170. Resulting direction.

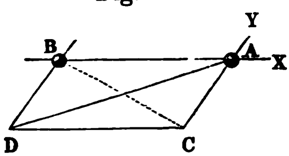
Fig. 35.



171. Suppose a ball A, to be at the same instant struck by two equal forces X and Y, the former moving in the direction B, and the latter in the direction C; the force X alone would carry the ball to B, and the force Y would carry it to C; but the joint action of the two forces will cause it to move in a diagonal line at an equal distance between them. If you draw a line from B, parallel to A C, and another from C parallel to A B, the two lines will meet in the point D, where the ball would stop. The figure A B D C is a square, and the line D A is the diagonal of a *square*.

172. In the example above given, the moving forces were equal. But suppose the force X to be twice as great as the force Y, it would drive the ball twice as far, consequently the line A B, (the distance to which the ball A would be driven by the force X) would be twice as long as the line A C (the distance to which the ball would be driven by the force Y.) The body, acted upon by the compound forces, would move in a diagonal line between the two; and by drawing a straight line from B, parallel to A C, and another from C, parallel to A B, they will meet in the point D, and the line D A is the diagonal of a *parallelogram*, whose length is double its breadth.

Fig. 36.



173. *Different forces act with greater power upon a moving body when the angle at which they meet is acute*, as they approach nearer to a union of forces, hence the diagonal or *resultant will be longer*, as may be seen in Figure 36. By rendering the angle B A C more acute, the diagonal or *resultant* would be longer, because the joint impression of the forces would be increased; therefore when this angle should entirely disappear, or in other words, when the sides A B and A C should coincide with the diagonal A D, the two forces would act in the same direction, and the moving body have the full effect of their joint forces; but this would cease to be an example of the *composition* of *forces*; it would be the complete *union of two forces*.

174. Again, *if the angle made by the direction of two forces be*

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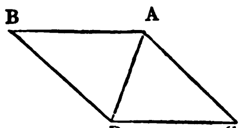
171. Example of motion caused by two equal forces.
172. Motion caused by two unequal forces.
173. Compound forces acting at an acute angle.
174. Compound forces acting at an obtuse angle.

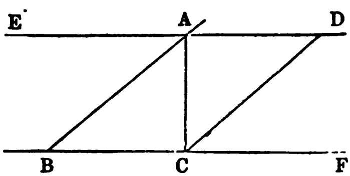
obtuse, as in the angle B A C, (Fig. 37,) *they approach to* *position of forces;* and the diagonal sultant A D is proportionally *shor* *When the forces* represented by the A B and A C, *meet without formin* *angle*, provided they are equal forces *act in direct opposition, and destro* *other*, consequently a body acted u A, would have no motion. But force be superior to the other, the does not move in a diagonal line, but in the direction greater force.

Fig. 37.



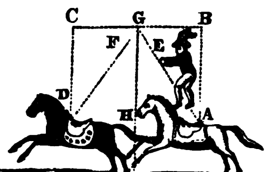
175. *When a body would describe the two sides of an equilateral t by two forces acting separately, it will, in the same time, describe a side, by the two forces actin ly.* Thus a boatman wis cross a river, from A to C, steer his boat directly tow so that his own force co with the force of the stream from E to A, or B to C, woul the boat to describe the diag C. The force of the strean would carry him from A to own force alone, would, same time, carry him to B; two forces compounded, wil him to C, in the same time as the one force would have carried him t the other to B.*

Fig. 38.



176. When the circus rider leaps over a rope, as his ho galloping at full speed, he comes down upon the saddle, des ing not in a perpendicular, oblique direction, *rising in one onal line* and *descending in an* If the horse were standing sti motion of the rider in leapin would carry him from A to the motion of the horse alone carry him directly forward; t agonal between the two forces line A G, by which he would while he would descend in the onal G D, through the joint effect of the force derived fro

Fig. 39.



* By a reference to Fig. 31, with the explanation, the pupil will comprehend how the parallelogram A B C D is obtained, and will p that the short diagonal A C, is made by the obtuse angle B A D, accor the illustration of Fig. 33.

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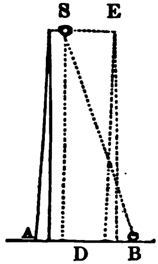
175. What proposition does Fig. 34 illustrate?

176. What case affords an experimental illustration of the paralle *of forces?*

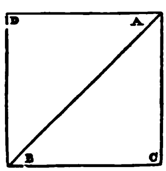
motion of the horse and his own weight, the former of which would tend to carry him from G to C, while the latter, alone, would impel him from G towards H. This case affords an experimental illustration of the *parallelogram of forces;* the sides of the parallelograms A B G H, and G H C D represent the quantity and direction of the two forces acting together.

Fig. 40.



177. A stone dropped from the mast-head of a vessel under sail, being affected by the motion of the vessel as well as by the force of gravitation, would not fall in a perpendicular, but in a diagonal line. Let A represent the mast, S the stone, D the deck, and the line S E will be the distance that the mast-head will have moved, while the stone would have fallen from the force of gravity alone, from S to the point under it on the deck; but the stone, partaking of the common motion of the ship, and impelled by gravity, takes a diagonal direction, in the line S B.

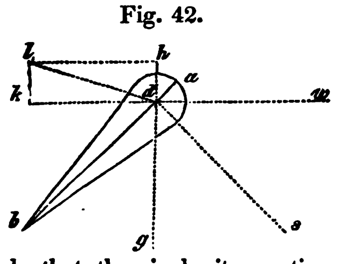
Fig. 41.



178. The navigator, in crossing the ocean, by observing the course of his ship, is able to determine the latitude and longitude. Thus if the course of his ship, according to observations made with the mariner's compass, has been, for a certain time, south-west, let D A and B C represent parallels of latitude, and D B and A C parallels of longitude, the diagonal line A B will describe the ship's course through the sea, and the difference of latitude and longitude at particular points of the vessel's track may thus be estimated.

Motion resulting from more than two forces.

Fig. 42.



179. *Bodies may be moved by the action of more than two forces:* A kite, in flying, is acted upon by *three forces*, the *string*, the *wind*, and *gravity* or, (which is the same thing,) its own weight. The boy, to make his kite rise, first balances it in an oblique position in the air, then runs with it a few rods, that the air, by its reaction, may throw it upwards. Let

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177. Would a stone dropped from the mast head of a vessel under sail, fall in a perpendicular line?

178. Course of a ship indicating latitude and longitude.

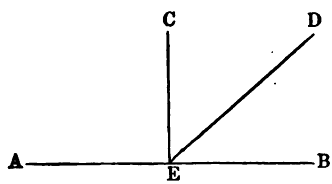
179. How many forces is a kite flying, acted upon? In how many directions is it acted upon?

a b represent a kite in the air, in a slanting position, or inclined towards the surface of the earth, at an angle of 45 degrees,* and let *d s* represent the string. Suppose the wind to be blowing in the direction *w d;* when it strikes the kite at *d* in the line *d h*, it will be reflected in the direction *d g;* and the force of the reflected wind, reacting on the kite in the opposite direction, will tend to carry it perpendicularly towards *h;* but the wind is also acting on the kite with direct force in the line *w d*, tending to carry it horizontally towards *k*, while gravity is tending to bring the kite to the ground, in the perpendicular direction, *d g*. It is then acted upon in *three directions, upward* toward *h*, *by the reaction of the reflected force of the wind, sideways*, or toward *k by the direct force of the wind*, and *downward*, or toward *g*, *by gravity.*

180. Suppose the weight of the kite pull it downward with the force of two pounds, and the wind act upon it upward, with a force equal to two pounds, and horizontally with the same force, it is evident that it will move horizontally; since the two forces, *d g* and *d h*, acting in opposite directions, would destroy each other, and leave the kite to be moved wholly by the force *w d.*

181. *But if the forces be unequal, the weight of the kite being but two pounds*, while the *horizontal, and upward force of the* wind are each equal *to four pounds*, the kite would then be impelled horizontally toward *k* with a force of *four*, and upward toward *h* with the force of *two pounds* (half the upward force being lost by the opposing weight of the kite); now, let the line *d k* be made twice the length of *d h* to represent double the force; then complete the parallelogram *d h l k*, the diagonal *d l* will represent the line in which the kite would move.

182. By letting the string of the kite fall from the hand, the resistance which it had offered to the wind would cease, and when this resistance no longer existed, there could no longer be any reflected motion; and the kite after being blown along by the horizontal action of the wind, would be brought to the earth by gravity.



* A B represents the surface of the earth, C the zenith or point directly over head, a line drawn from which makes, with the surface of the earth, the angle C E B, or an angle of 90 degrees. The line D E forms with the same, the angle D E B, of 45 degrees.

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180. When would a kite be made to move horizontally?

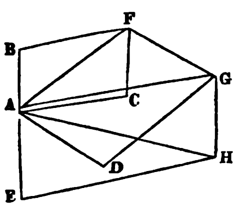
181. What would change the horizontal motion into a diagonal, upward motion?

182. Effect of letting the string of the kite loose. Effects of the wind *upon the motion* of the kite.

By holding the string very tight, the horizontal force of the wind ceases to act upon the kite, and the reflected force raises it perpendicularly. When a kite rises suddenly in a perpendicular direction without the string having been pulled, it is because its reflected force is increased by an increased velocity of the wind; when the kite descends without any slackening of the string, it is owing to a lessened force of the wind, or to a change in its direction.

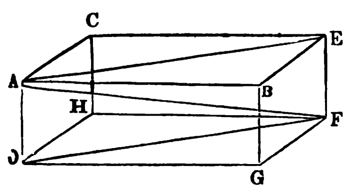
183. The combined effect of three or more forces acting on a body in different directions, may be discovered by means of the parallelogram of forces; and a single force may be thus assigned which will be the resultant of those forces. This may be done by obtaining first the diagonal, representing the resultant of the combination of two forces, and considering that diagonal as the side of a parallelogram, of which a line representing a third force will form one of the other sides, and the parallelogram being completed, the diagonal will be the resultant of the first three forces; and the operation may be extended in the same manner so as to discover the ultimate resultant of any given number of forces.

Fig. 43.



Let the point A be impelled by forces in the directions A B, A C, A D, and A E; then, to find out the resultant of these combined forces, complete the parallelogram C A B F, and the diagonal A F will exhibit the result of the forces A B and A C. Complete the parallelogram D A F G, and its diagonal A G will denote the result of the three forces A B, A C, and A D. In the same manner, complete the parallelogram E A G H, and the diagonal A H will represent the force compounded of all the four forces, A B, A C, A D, and A E. But the construction may be simplified by merely drawing the lines B F, equal and parallel to A C; F G corresponding with A D; and G H, bearing the same relation to A E; then, the line joining A and H, which as before will express the resulting force.

Fig. 44.



It may be demonstrated by means of the parallelogram of forces, that from three forces acting in the directions A B, A C, and A D, in the proportions of the length, breadth and depth of a parallelopiped,* will result a motion in the diagonal A F of that parallelopiped; for A B and A C compose A E, and A E and A D compose A F; which last is the resultant of the moving forces in the directions of the three sides of the parallelopiped.

The effect of the composition of forces, when a body impelled in different directions takes the course in a diagonal line between the two impelling forces, may be thus experimentally exemplified.

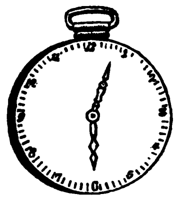
* A parallelopiped is a regular solid comprehended under six parallelograms, the opposite ones of which are similar, parallel, and equal to each other.

183. Parallelogram of forces. Explain Fig. 43. Explain Fig. 44.

LECTURE VIII.

ACCELERATED AND RETARDED MOTION.

Fig. 45.



184. *Uniform motion*, is that, by which *a body passes over equal spaces in equal times;* as the minute hand of a watch or clock, which, in sixty minutes, passes through a given circle. The hour hand has also a uniform motion, though much slower, since it passes through the twelfth part of the circle only, while the minute hand passes through the whole;—the relative velocity of the hour hand is, therefore, twelve times less than that of the minute hand.

185. A body once set in motion, would continue to move forever with uniform velocity, but for the resistance of the air, friction, gravity, &c., from the influence of these causes, there must be, in order to produce uniform motion, the *constant exertion of a uniform force.*

186. The uniform motion of a watch is produced by a force (the *spring*) acting upon the wheels, in a steady and uniform manner. A horse, moving at the rate of six miles an hour, goes with a uniform velocity, caused by the continued exertion of muscular strength.

187. *A body descending by gravity is not acted upon, by one impulse merely*, but by a continued series of impulses, each added to the previous ones. If a ball rolling upon smooth ice were every instant to receive a new stroke, retaining all the previous momentum and continually receiving more, its velocity would soon become very great. Thus a falling body is continually receiving new velocity and momentum from gravity.

Spaces described by Falling Bodies.

188. *The spaces described by bodies falling from a state of rest by the influence of gravity, are as the* SQUARES OF THE TIMES, *during which, they are falling.*

A stone falling from a high tower, will, in two seconds, fall *four* times as far as in one second; in three seconds, nine times as far; in four seconds, sixteen times as far; and in ten seconds one hundred times as far; because the square of 2 seconds is 4 of 3 is 9, of 4 is 16, and of 10 is 100 seconds.

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184. Uniform motion.
185. What is necessary to produce uniform motion?
186. Examples of uniform motion.
187. Falling bodies continually acted upon by new impulses.
188. Proposition concerning the relation between the *spaces* and *times* of *falling* bodies.

189. It has been proved by experiments, that a body falling from a state of rest, passes through 16 feet* the first second of time; in two seconds, it passes through 4 times 16, or 64 feet; and in three seconds (multiplying by 9, which is the square of 3), it passes through 144 feet; and in ten seconds (multiplying 16 by the square of 10), 1600 feet. Therefore, to find the *number of feet* through which a body has fallen, the *time* being known, *multiply the* SQUARE *of the number of seconds by* 16. The spaces being proportioned, not simply to the times 1, 2, 3, and 10, but to the squares, 1, 4, 9, and 100.

Ex. Suppose a body to have been falling 5 seconds; through what space has it fallen? *Ans.* 400 feet.

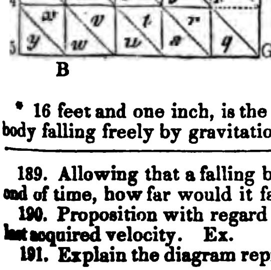
Velocity of Falling Bodies.

190. *If a body, having fallen through a certain space in a given time, should receive no farther impulse from gravity, but proceed on, uniformly, with the last acquired velocity, it would describe* TWICE THE SPACE *through which it had passed, in the same time as that, during which it had fallen to acquire that velocity.*

Ex. Suppose a body, at the end of *one* second, to have fallen 16 feet, it would have acquired a velocity which in the *next second* would carry it 32 feet; at the end of *four* seconds, its space, multiplying 16 by the square of 4, being 256 feet, the next four seconds it would descend 512 feet, or *twice the space in the same time as that during which it had fallen to acquire that velocity.*

Time, Space and Velocity.

Fig. 46.



191. The line A B represents the TIME in which a falling body descends, divided into seconds; the horizontal lines 1 C, 2 D. 3 E, 4 F, and 5 G, represent, by their increasing lengths, the VELOCITY acquired in each second. The small triangles represent SPACES. By multiplying 16, the number of feet in which a body falls the first second, by the number of triangles in each line, we learn the space passed through in each second. In the first second we have 1 triangle *a*; in the next second we have 3 triangles *b c d*; in the third second we have 5 triangles, *e f g*, &c.; in the fourth second we have 7 triangles, *j k l*, &c.; and in the fifth second we

* 16 feet and one inch, is the exact distance through which, it is proved, a body falling freely by gravitation, passes, the first second of its descent.

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189. Allowing that a falling body would pass through 16 feet the first second of time, how far would it fall in ten seconds? Ex

190. Proposition with regard to the motion of a body proceeding with the last acquired velocity. Ex.

191. Explain the diagram representing *time*, *space*, and *velocity*.

have 9 triangles, *q r s*, &c., the spaces in each successive second increasing in proportion to the series of *odd* numbers, 1, 3, 5, 7, 9, &c. That is, during the first second, the body falls a certain distance, say 16 feet; during the next second it falls *three* times as far; during the third, *five* times as far; during the fourth, *seven* times as far; during the fifth, *nine* times as far, and so on in the same proportions. The odd numbers, 1, 3, 5, &c. are the ratios or proportions in which the velocity of falling bodies is uniformly accelerated.

192. *Rule.*—If a body fall 16 feet the first second, in the *second* second it will fall 48 feet, or 16 multiplied by 3; in the third second it will fall 80 feet, or 16 multiplied by 5, &c.

Through how many feet would a body descend the fifth second of its fall? *Ans.* 144. We multiply 16 by 9, because the body falls nine times as far during the fifth second, as the first.

193. If it be required to find the *whole space* through which a body has fallen during five seconds *of time*, multiply 16 by the square of the time; the square of 5 being 25, the answer would be 400 feet.

194. The following Table may illustrate this subject:

Seconds of descent.	Feet passed through at the end of each second.	Final velocity in each second.	Feet passed through during each second.
1	16	32	16.
2	64	64	48.
3	144	96	80.
4	256	128	112.
5	400	160	144.

The first column of figures stands for the *time of descent* of a falling body, as divided into seconds.

The second column of figures shows the whole *number of feet* through which the falling body has passed at the end of each second; these numbers are obtained by multiplying 16 by the square of the figure in the first column, according to the following rule: *the whole spaces passed through are proportional to the squares of the whole times.*

The third column of figures shows the final velocity in each second; these numbers are obtained by multiplying 16 by the even numbers 2, 4, 6, 8, &c., according to the following rule: *the velocity passed at the end of any number of seconds, is represented by twice that number multiplied by* 16; as the final velocity at the end of two seconds is 64, or 16 multiplied by twice 2.

The fourth column of figures shows the feet passed through during each second; the numbers are obtained by multiplying 16, by the series of odd numbers which represent the ratio of acquired velocities, according to the following rule: *the spaces through which a falling body passes in a succession of equal intervals are in the proportion of* 1, 3, 5, 7, 9, 11, &c.; the number of feet passed through in each second is 16 less than that of the final velocity; that is, the body has acquired during the last second of its fall a velocity

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192. If a body fall 16 feet the first second, how many will it fall the second and third seconds? How many the fifth second?

193. How can you find the whole space through which a body has fallen during five seconds?

194. Explain the table. The first column of figures. The second column of figures. The third column of figures. The fourth column of figures.

which, without any new impulse from gravitation, would, in the next second, carry it 16 feet farther than it moved the preceding second.

195. *The spaces described by falling bodies,* are proportioned to the* SQUARES OF THE VELOCITIES *which they acquire, in falling over those spaces.*

Rule.—Divide the square of the velocity by 64.

Ex. If a ball, falling from the summit of a tower, acquire a velocity of 80 feet, what is the height of the tower? *Ans.* The square of 80 is 6400, which divided by 64, equals 100 feet, the height of the tower. *Ans.* $80^2 \div 64 = 100$.

196. In all computations respecting the velocity of falling bodies, the essential points are, to know the *space fallen through in one second, and the acquired velocity during that time.* The *height* of a tower or precipice, or the *depth* of a well or cavern, may be easily computed by marking the *time* in which a body falls from the top to the bottom; or if the *height* or *depth* be known, the *time* in which a body would fall to the bottom may be ascertained.

Ex. If a stone let fall from the top of a well, is 4 seconds in reaching the bottom, what is the depth of the well?

Multiplying the square of the number of seconds by 16, we find the depth of the well to be 256 feet: for the square of 4 is 16, which, multiplied by 16, equals 256 feet; therefore, $4^2 \times 16 = 256$ ft.

197. Though the resistance of the air in impeding the velocity of falling bodies, has not been calculated in our computations, this has some effect, even in the case of the heaviest substances. By the expression, "*a body falling freely by gravitation,*" is to be understood, a body falling in a *vacuum.* It is proved, by the experiment of a piece of lead and a feather falling in an exhausted receiver, that the *velocities of all bodies falling, in a vacuum, from the same height, are equal;* as the attracting force which acts upon the greater mass exceeds that which acts upon the less, as much as the greater body exceeds the less, in quantity of matter.

* A body moves 16 feet during the first second, and 48 during the next second, therefore it acquires a velocity of 32 feet in passing over 16 feet; hence the square of the acquired velocity or $(32)^2$ bears the same ratio to the space, viz. 16 feet, that the given acquired velocity bears to the required space. Let 40 feet be the acquired velocity, then we shall have the proportion $(32)^2 : 16 :: (40)^2$ is to the required space. Since the first term of this proportion or $(32)^2 = (16 \times 2)^2 = 2^2 \times 16 \times 16$, we can divide the terms of the first ratio by 16, and the proportion becomes $2^2 \times 16 : 1 :: 40^2$ is to the required space, as $2^2 \times 16 = 64$, hence, $64 : 1 :: 40^2$ is to the required space, $40^2 = 1600 \div 64 = 25$ feet. From this we derive the following rule, for finding the spaces described by falling bodies when the acquired velocity is known.

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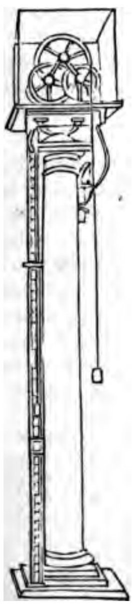
195. Proposition concerning the spaces described by falling bodies. Rule. Ex.

196. Essential points in computing the velocity of falling bodies. Ex.

197. What is meant by bodies falling freely? When are the velocities of all bodies, falling from the same height, equal?

198. The accelerated motion of falling bodies is familiar to every observer of nature:—an apple falling from the top of a high tree, is at first visible to the eye, but it soon acquires so great velocity, as to render it indistinct to the sight, and only the line of its descent is visible. Let a fragment of a rock be pushed from the height of a precipice; at first its speed is not very great, but it soon begins to move more rapidly, and gathering new velocity at every instant of its fall, it rushes downward with tremendous force. Boys accustomed to slide down hill upon their little sledges, are familiar with the fact that the velocity acquired in their descent, carries them on some distance after they have reached the foot of the hill, and even some way up an acclivity. When standing by a waterfall of considerable height, we may first see the water slowly descending in one sheet, but as the eye follows its downward course, we perceive the force and velocity becoming greater at every instant, until, seen only as foam or mist, it dashes into the chasm below and mingles with the current.

Fig. 47.



199. *Calculations respecting falling bodies* have been rendered very accurate by Attwood's* machine, by means of which the *descent of falling bodies* is made so *gradual*, that the relations between *times and spaces*, can be accurately determined; for though the motion is retarded, these relations remain unchanged. The machine consists of a wooden column about ten feet high, with a rod marked by feet and inches, and two weights suspended over pulleys. The rapidity of the falling motion in the heavier weight is retarded by the lighter weight; thus the increase of velocity is so gradual that it may be seen by the naked eye, as the weight descends along the graduated rod, while the seconds of time may be noted by listening to the beats of a clock attached to the machine.

Retarded Motion.

200. *The ascending motion of bodies thrown upward, is retarded in the same proportion as the motion of falling bodies is accelerated.* The same laws that regulate uniformly accelerated velocities, apply equally to uniformly retarded velocities, the motions being reversed.

* George Attwood was Professor of Natural Philosophy, at Cambridge, England, in 1784.

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198. Examples of accelerated motion.
199. The size and construction of Attwood's machine
200. In what proportion is upward motion retarded?

Fig. 48.

201. Suppose that a body thrown from A, perpendicularly upward, moves with a force sufficient to carry it, in the first second to B, in the second to C, in the third to D, and in the fourth to E, the motion, which has been, uniformly, growing less, here ceases, and gravity, having now wholly overcome the *projectile force*, operates without opposition. The body begins to fall, and, at every instant, receiving from gravity a new momentum downward, passes through the *same spaces* in the same *times*, as in its ascent; that is, it falls from E to D in the first second, from D to C in the next, from C to B in the third, and from B to A in the fourth.

202. The projectile force is that which impels the body; it may be greater or less, as a bullet thrown upward with the hand, moves with little force compared with the momentum of a bullet shot upward with a gun. In the former case, the velocity would be less than in the latter, in proportion as the projectile force was less; the space through which it would move would be less in the same ratio, as would also be the time which would pass before it reached the ground. If one body be shot upward with twice the force of another, it will rise twice as high; if shot with ten times the force it rises ten times as high.

203. Suppose an arrow shot upward from a bow fell to the ground in six seconds, how many feet did it ascend? *Ans.* The times of ascent and descent being equal, the arrow was three seconds in rising, and three in falling. It has been shown that, in order to know the spaces described by a falling body, we must multiply the squares of the *time* by the velocity, which in bodies falling by gravitation, is 16 feet the first second; the square of 3 (the number of seconds in which the arrow was falling) is 9; this multiplied by 16 gives 144, which is the number of feet the arrow fell; consequently it must have risen to the same height, that is 144 feet.

LECTURE IX.

CURVILINEAR MOTION. PROJECTILES.

204. *Curvilinear Motion*, or motion in curved lines, is the result

201. Explain Fig. 48.

202. On what does the velocity of a projectile depend?

203. To what height must a body have ascended which falls to the ground in six seconds after it was thrown upward?

204. Cause of curvilinear motion. Stone whirled in a sling. Ball revolving in a hoop.

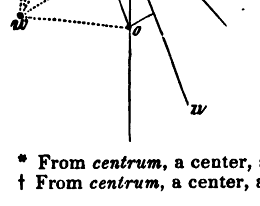
of two forces acting on a body; by one of which it is projected forward in a right line, whilst by the other, it is drawn or impelled towards a fixed point. When either of these forces ceases to act, the body will move in a straight line. A stone whirled in a sling, is acted upon by two forces, that of the hand, which represents the projectile force, and that of the string, which causes it in its motion to describe the circumference of a circle; but if the string break while the stone is thus whirling, the stone would fly off in a *tangent*, being then acted upon only by the projectile force.

If a ball be made to revolve within a hoop laid flat upon a table, it will manifest a constant tendency to escape from a circle in which it is moving, by pressing against the sides of the hoop. It is evident that if the hoop be lifted up while the ball is revolving, the circular motion will be destroyed and the ball fly off in a right line from the point where it is set free; and this line will form a tangent to the circle in which the ball had moved.

205. Thus we find curvilinear motion to be produced by two antagonist powers; the one, which *draws the moving body towards the center of motion is called the centripetal** force, and *the other, which is constantly tending to drive it from the center, is called the centrifugal*,† and sometimes the *tangential* force, because the line of its direction is that of a tangent to the circle. These two forces are also called, *central forces.*

206. Motion in a circle is, at every successive instant, a *bent motion;* for a circle is made up of an infinite number of straight lines, and a constant force is necessary to counteract the tendency of the body to pursue these straight lines.

Fig. 49.



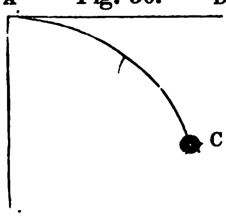
Suppose a body, *a*, to be projected in the direction *a b*, and at the same time to be attracted with equal force by *w;* it will obey neither force, but *move* towards *d* in the diagonal of a parallelogram, whose sides *a c*, and *a p*, are in proportion to the two forces *a b*, and *a w*, and whose other two sides are obtained by producing *p* and *c* to *d*. The body would now continue to move tow-

* From *centrum*, a center, and *peto*, to tend towards.
† From *centrum*, a center, and *fugio*, to fly from.

205. Centripetal and centrifugal forces.
206. Tendency of a body to follow straight lines. Illustrate by Fig. 49, the cause of circular motion. Motion of the moon.

ards *m*, if its motion were not bent by some new force; but at *d*, it receives a new impulse from *w* tending to carry it in the direction *d w*, it therefore describes a new diagonal *d g*, and we have a second parallelogram by producing *e* and *f* to *g*. At *g*, a new impulse is received from *w*, and the body, instead of moving in a straight line towards *i*, describes a new diagonal, *g k*; here a new impulse from *w*, bends the motion from the straight line *k n*, and carries the body on in a new diagonal to *o*. The line *o w* is shorter than *a w*, because *a*, the body acted upon, is supposed to receive from *w* a succession of impulses, while no new action is received from *b*. If we suppose *w* to be the sun, and *a* the earth impelled in its course by a projectile force at *b*, and a centripetal force at *w*, we have the *elliptical* orbit of the earth, or the path in which she moves round the sun. The earth, with this centripetal force continually acting and increasing as she approached the sun, would be precipitated upon it, but for the law of nature which causes an increase of the centrifugal force to follow increased velocity.

Fig. 50.



The motion of the moon around the earth, is in a curvilinear line, produced by the action of the centrifugal force A D, and the centripetal force A B; the latter, which is the earth's attraction, operating constantly, causes the moon to describe the curved line A C.

207. The centrifugal force of bodies revolving in a circle, is proportioned to their *specific gravities*. Thus, if cork, water, and quicksilver be whirled together in a pail, they will arrange themselves in the inverse order of their specific gravities. This experiment may be performed by suspending the vessel by a cord from some fixed point, and twisting the cord by turning the pail; when the cord is let go, it untwists itself, giving a rapid, whirling motion to the vessel. This revolution carries the heaviest body, viz., the *quicksilver*, *farthest from the center* of the vessel or next its sides; the *water will be intermediate* between the quicksilver and the cork, and the *cork in the center of the vessel*. If the pail contain water only, this, by the untwisting of the cord, will sink in the center and rise towards the side of the pail, or where the *centrifugal force* is greatest. Thus we see that the centrifugal force tends to cause bodies to recede from a central point.

208. The centrifugal force is *increased by increasing the velo-*

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207. What causes the elliptical orbit of the earth? Why is not the earth precipitated upon the sun by the superior force of the centripetal power?
208. Centrifugal force proportioned to velocity.

city of a revolving body; or, the centrifugal forces are proportioned to the *squares of their velocities.* If the velocity be increased 4 times, the centrifugal force will be 16 times greater; if increased 10 times, the centrifugal force will be 100 times greater. The revolutions of the pail, by the untwisting of the suspended cord, may be so rapid as to cause a small quantity of the water, not only to rise to the edge of the pail, but to be thrown off in straight or tangent lines. If a pair of tongs be suspended in the same manner as the pail, and made to turn by the untwisting of the cord, the legs will separate with a force proportioned to the velocity of the rotation. When this rotation ceases, they will resume their former situation.

209. An application of the principle above stated to mechanics, is seen in the *regulator*, an important invention for regulating the supply of steam, in steam engines. It consists of two heavy balls *a b*, so connected with a perpendicular shaft, as to fall parallel to the shaft when at rest; but when they are made to revolve by the motion of a common axis, the balls *diverge by the centrifugal force.* By connecting the regulator at *c*, with an important part of the steam engine called the *fly wheel*, it is made to partake of the common motion of the engine; and, while the motion is uniform, the balls will remain at a certain distance from the perpendicular shaft. By an increase of steam, the motion becomes more rapid; this causes the balls to *diverge* farther from the perpendicular, and, in so doing, *raise a valve* connected with the boiler, by which such a portion of steam is let off as will suffer the balls to resume their usual position; and this position indicates that the velocity of the motion is reduced to the rate required.

Fig. 51.

Regulator.

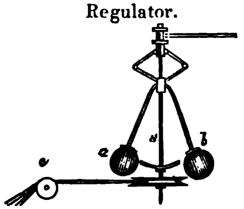
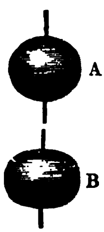


Fig. 52.



210. If a ball of wet clay A, be made to revolve rapidly upon an axis, it expands at the middle, and becomes flattened at the two ends, as at B. This is because the middle, being farther from the axis of motion, has a greater velocity, and, of course, greater centrifugal force. The ball A, may be supposed to represent the figure of the earth when it first began to revolve on its axis, and B to represent its figure as it exists at present, elevated at the equator and flat-

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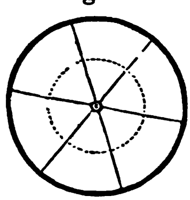
209. Regulator of the steam engine.

210. Effect of centrifugal force upon the form of a ball of wet clay. Figure of the earth. Oblate and prolate spheroids.

tened at the poles.* This figure is that of an *oblate spheroid.* A spheroid differs from a sphere or globe, in being flattened in one direction, and lengthened in another. An orange is an *oblate* spheroid. A lemon, being elongated towards the ends, is a *prolate* spheroid.

211. It has been proved, by accurate calculations, that, if the revolution of the earth on its axis were but seventeen times faster than it now is, bodies at the equator would be acted upon by centrifugal force as much as by gravity, in which case they would have no weight. A farther increase of velocity would cause them to rise and form a ring round the earth, like that which surrounds the planet Saturn, or to fly off in pieces which might revolve around the earth, like so many little moons.

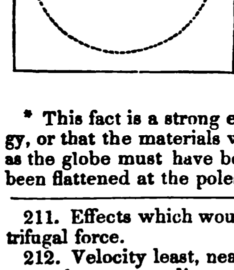
Fig. 53.



212. In order to explain how one part of a revolving body moves with greater velocity than another, we will illustrate the subject, by the motion of a wheel. In each revolution, the circle to be described is small in proportion as it is near the axis of motion or center of the wheel, which is, itself at rest; and, as the greater spaces are passed over in the same time as the smaller, it follows, that the velocity must be greater in proportion; and the centrifugal force increasing with the squares of the velocity, this force must be greatest at the rim of the wheel, or where the circle is greatest.

213. By the *axis of motion*, is understood a *line* either real or imaginary, round which a body turns. If an apple be turned upon a wire passing through it, the wire is the axis of motion. By the axis of the earth's motion is understood an *imaginary line* through its center.

Fig. 54.



214. The *center of motion*, is a *point* round which a body turns, or on which it rests, while revolving. Suppose that upon the table A D, is fastened a string, C, having at one end an ivory ball, B. To this ball, a forward motion being given with the hand, it is evident that the ball

* This fact is a strong evidence in favor of the Wernerian theory of geology, or that the materials which compose the earth were once in a fluid state; as the globe must have been like the ball of soft clay, in order thus to have been flattened at the poles.

211. Effects which would be produced by an increase of the earth's centrifugal force.

212. Velocity least, nearest the center of motion. Centrifugal force greatest at the greatest distance from the center of motion.

213. Axis of motion. Axis of the earth's motion.

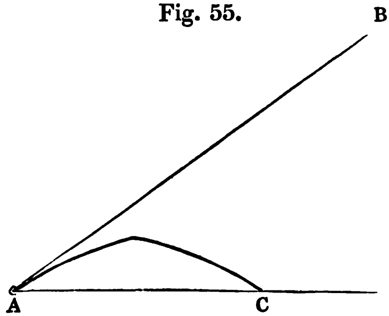
214. Center of motion.

will revolve in a circle. The force of the hand is the *centrifugal force*, and the confinement in which the ball is held by the string, is the *centripetal force*. The point C is the *center of motion*.

PROJECTILES.

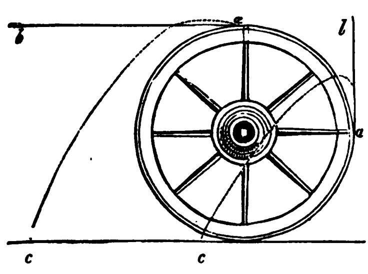
215. Any body thrown, or projected, either obliquely, or horizontally, is a *projectile*. Projectiles move in a curvilinear path, and the curve which they describe is called a *parabola*. Suppose a body to be thrown obliquely upward, in the direction A B, the force of gravity will immediately begin to draw it toward the earth; and as this force is at every instant increasing the motion of the falling body, it will, at every succeeding instant, recede more and more rapidly from the line A B, thus describing the curve A C, which is continually deviating from the line of projection. until it reaches the ground at C. The *random* of a projectile is the horizontal distance between the point from which it is thrown, and that where it falls; thus the line A C, is the random of a projectile thrown in the direction A B.

Fig. 55.



The mud thrown from a carriage wheel describes a parabola, as in the lines *a c* and *a c;* whereas it would be thrown in the straight lines *a b* and *a b*, were it not for the continual action of gravity.

Fig. 56.



216. Projectile motion does not impede the action of gravity, and hence a cannon ball shot horizontally over a level plain, will touch the ground

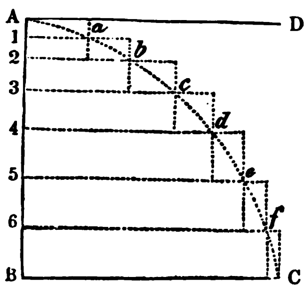
215. What is a projectile? A parabola? What is meant by the random of a projectile? Line described by mud thrown from a carriage wheel.

216. Does projectile motion impede the action of gravity? Examples. Explain the diagram to demonstrate that a *projected body* will reach the ground at the same instant as *one which falls* from the same height, and at the same time.

as soon as another ball, dropped at the same instant from the cannon's mouth. The body moving forward is going *downward* at every instant, as rapidly, as if it had no other, than the downward motion. Suppose one stone to be *projected* directly forward from the top of a high tower, and another, at the same instant, to be *dropped* directly downward, both stones will reach the ground at the same moment.

If A D be the horizontal line of projection, and A B the perpendicular line of gravitation, then the stone which is projected will not move in either line; but in A C, which is the result of the projectile force, and the force of gravitation combined; and it would pass through the space A a, in the same time that gravity, alone, would carry the other stone from A to 1. When, therefore, the one stone is at b, the other is at 2; in like manner, c corresponds to 3, d to 4, e to 5, and f to 6. Thus, the stone which was projected from A, touches the ground at C, in the line A C, at the same instant that the stone which was dropped touches the ground at B.

Fig. 57.



217. The study of projectiles is an important part of military science. In firing at distant objects, it is necessary that the engineer should know, not only in what situation to place his cannon in order to give the required direction to the ball, but should know the velocity with which it will move, that he may thus be enabled to calculate *the curve it will describe* in its transit, and, consequently, the spot where it will strike. In cannonading a city, a great advantage is gained by an elevated position, because projectiles thrown from such a point, take effect at a greater distance than if thrown from a level; as a stone projected from the brow of a hill, moves with much greater force and consequently over more space, than if thrown by a person standing upon a plain. A cannon ball shot horizontally from the top of one of the highest points of the Andes, would move three or four miles before striking the earth.

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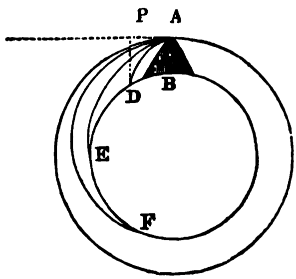
217. Connection of the study of projectiles with military science.

Fig. 58.



218. Suppose a body placed at the point A, above the surface of the earth ;—if it were let fall with no projectile force, gravity would cause it to descend with an accelerated motion toward the earth's center, in the perpendicular direction A B. But if the body were impelled by a projectile force in the direction A P, it would descend in the curve line A D. The greater the projectile force A P, the greater will be the sweep of the curve line. A greater degree of force would send the body to E, and a still greater degree of force would send it to F. If the velocity of projection were increased to a certain amount, the body would reach the antipodes at C, and even continue its course round the globe until it returned to the point A, whence it started. Were it not for the resistance of the air, a projected body, which now moves only three or four miles before falling, would go nearly forty miles ; and, could it be impelled with ten times the velocity of a cannon ball, the centrifugal and centripetal force would be in equilibrium, and, by their mutual action, cause the body to revolve as a satellite around the earth.

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218. Explain Fig. 58.

PART II.

OF THE MECHANICAL POWERS.

LECTURE X.

MACHINES.—THE CORD.—THE LEVER.

219. SCIENCE would be of little use to man, were it not capable of practical application. The subjects which we have considered, viz: gravity, force and motion are, highly interesting as parts of a system of Philosophy, and because they explain many of the phenomena of nature. But we are not placed in this world merely to be amused, and that Philosophy which has no higher object would be scarcely worth the name. Knowledge is valuable, in proportion as it contributes to the comfort and happiness of man, or elevates and ennobles his soul. We have many wants, which can be supplied only by labor and industry; such inventions, therefore, as tend to facilitate labor, and give effect to industry, are of great value. We are indebted to science for most of those improvements in the arts and manufactures, which give to the moderns such great advantages over the ancients; not only in supplying necessary wants, but in greatly increasing facilities for the acquisition of knowledge, and in adding to the enjoyments and luxuries of life.

220. The department of Natural Philosophy called *Mechanics*, exhibits the principles which are applied to the construction and operation of machines. The utility of machinery consists in the addition which it makes to the power of man. Under his control its practical results are, economy of time, and the application to valuable purposes, of many substances, which would, otherwise, have been useless.

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219. Importance of the practical applications of science.
220. Mechanics. Utility of machinery.

221. Man, besides human strength and the strength of other animals, has at his command the power of *water*, *wind*, and *steam*, with the force of *springs* and *weights*. *Water* acts by its *weight*, and the *velocity* which it acquires in falling. *Wind* acts by its *volume* or *mass*, and its velocity. *Steam*, which is the vapor of water produced by heat, has a tendency to expand itself, and its force is proportioned to the heat which generates it, and the pressure to which it is exposed. The strength of *animals* is commonly made to act upon some center of inertia, by drawing, pushing or pressing.

222. There are three important circumstances to be considered in machinery; 1st. the weight to be raised, or the resistance to be overcome; 2d. the power by which this is to be effected; and 3d, the instruments employed.

223. In machinery, it is necessary that *motion should be produced, and this motion properly applied.* The instruments employed for communicating motion, are called by various names. A *tool* is the most simple instrument, and is generally used by the hand; as, a shoemaker's awl, a carpenter's saw. A *machine* is a complex tool, or a collection of tools, frequently put in action by inanimate force; as a carding machine, which is moved by the force of running water. An *engine* is a powerful and complicated machine, as the steam engine.

224. The ancients made little use of machines except in war, and in the erection of their stupendous works of architecture; and these machines were chiefly moved by the strength of men and animals. In building the Pyramids of Egypt, it is said that 100,000 men were employed for twenty years; it is estimated, that, by the aid of modern machinery, one man could now, in the same time, perform the labor of 27,000 of the Egyptian workmen.

225. Machines were *first invented* by men for the purpose of raising great weights, and overcoming great resistances. *They do not produce power, but modify its effects;* that is, they increase or diminish the velocity of the moving power, change its direction, and accumulate momentum in order to exert it at one single effort; or they distribute force among a great number of resistances, so dividing the force of resistance that it may be overcome by a series of actions, or by the continual action of the moving power. The term *mechanical powers*, is applied to a few simple machines,

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221. The forces under the control of man. How do these forces operate?
222. What circumstances are to be considered in machinery?
223. What is necessary in machinery? Instruments employed for communicating motion.
224. Machines of the ancients. Advantages of modern machinery.
225. Machines, why invented? Do they produce power? Why is the term *mechanical Powers* improperly applied?

which are either used singly, or, are variously combined to form complex machines. But these machines are not, in reality, powers, neither do they create power; but aiding man so greatly in the adaptation of the powers of nature to his use, they have been regarded as the prime agents, when, in fact, they are only secondary, and subservient to the existing powers of nature.

226. The simple mechanical powers are, the *Cord*, the *Lever*, and the *Inclined Plane*.

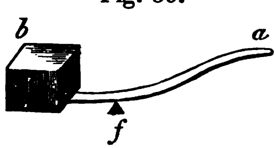
The Cord.

227. If a man wished to transport any weight, as a log of wood, without the assistance of the mechanical powers, he would first *lift* it with his hands, and then *carry* it in his arms. Here the muscular force of the man would be applied merely to overcome gravity, and would, consequently, act in a *vertical direction*. Were a *cord* to be tied to the log, and the strength of the man exerted in *pulling*, the direction of the force would then be *horizontal*. The cord would serve to change the *direction of the force*. The manner in which this force is modified is thus; instead of overcoming the weight of the log, or *gravity*, it only overcomes *friction*, which, though *proportional to the weight of a body*, is not equal to it.

The Lever.

228. *The lever is a rod or bar, which is used in raising a weight, or overcoming a resistance by being placed on a fulcrum or prop; which point is the center of motion.* The name *lever* was given, because this mechanical power was first applied only to the raising or lifting of weights. The center of motion is the *fulcrum*. The force which gives motion, is called the *power*, that which resists it is called the *weight*, or *resistance*; *a* is the part of the lever at which the *power*, or the strength of a man's hand, is applied; *f* is the *fulcrum*; and *b* the *weight*.

Fig. 59.



229. The lever changes the direction of forces into opposition; that is, when the *power descends*, the *resistance ascends*, viz., as the man's force presses down the lever, the weight rises.

The beam of a common balance is *a lever with equal arms;*

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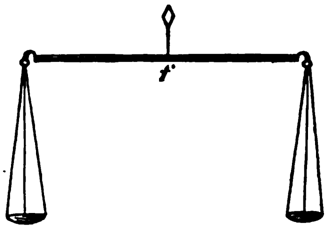
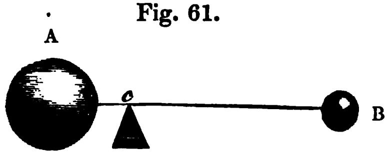
226. What are the simple mechanical powers?
227. Use of the cord.
228. What is the lever? Explain the terms, fulcrum, power, and weight.
229. How does the lever change the direction of the forces? How may a common balance be regarded as a lever? Effect of placing the fulcrum nearer the weight. How may a bar connecting unequal weights be put in equilibrium?

Fig. 60.



the point *f*, by which it is supported is the fulcrum. When the scales are empty, or when they contain equal weights, they are in *equilibrium;* the center of gravity, which is then in the middle of the beam, being supported by the fulcrum *f*. If one scale contains a greater weight than the other, the center of gravity is not in the middle of the rod, but nearer the greatest weight, which descends because it outweighs the mass in the other scale. Now if the fulcrum be removed and placed nearer the greater weight, the scales may be made again to balance each other; from whence it appears, that the *nearer the weight is to the fulcrum, the more its resistance is diminished.*

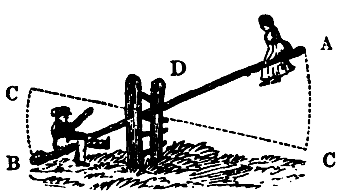
Fig. 61.



If the ball A weighing *three pounds*, and B weighing *one pound*, be fixed to the opposite ends of an iron bar, the bar will be in equilibrium if supported at the point *c*, *three times as far from the lighter ball as from the heavier one.* We may consider the bar as a lever, the large ball as the *resistance* or *force* to be overcome, and the supporting point as the *fulcrum.*

230. It is a fact well understood by children in amusing themselves by balancing upon a board placed across a prop, that when their weights are not equal, the heaviest shall be nearest the fulcrum, or center of motion. Now the child at A, *moves with greater velocity* than the one at B, because the former, in rising and falling, describes the arc of a larger circle, the two parts of the lever being considered the radii of two circles. If A D, represent the arm of the lever

Fig. 62.



230. How does the lighter child balance the heavier one in the see-saw. Effect of velocity. The length of the lever should be proportionate to the weight to be raised. How might a number of children at either side of the fulcrum balance each other?

supporting the lesser weight, this will be a radius of a larger circle; and B D, on which the greater weight moves, will be the radius of a smaller one; A C being an arc of the larger, and B C, an arc of the smaller circle.

Thus we see that by means of the lever, properly adjusted, the lighter child balances the heavier one; and because the lighter weight, in rising and falling, describes in the same time the arc of a greater circle than the heavier weight, the former moves with greater velocity; *velocity here being equivalent to weight.* Great weights may be raised with long armed levers, since the longer the arm to which the power is applied, the greater is the effect produced by it; because the velocity of the power is thus rendered proportionally greater than that of the weight. In the example of the children and the balancing board, the heavier child is to be considered as the *weight*, or resistance, and the lighter child the *power.*

A number of children might be placed at either side of the fulcrum provided that the *sum of the weights* of all on one side, *multiplied by their respective distances from the fulcrum, were equal to the sum of the weights of those on the other side* multiplied *by their distances*, respectively, from the same point. If a plank be twelve feet long, and the fulcrum be placed four feet from the end B, (see Fig. 62,) a child weighing 30 pounds at the end A, would support two children weighing 40 pounds each, one being placed at B, and the other two feet nearer the fulcrum. This will appear from calculation, for the weight of the child at A, 30×8, his distance from the fulcrum, gives for the product 240; and the weight of one child, $40 \times 4 = 160$, and another at two feet from the fulcrum, $40 \times 2 = 80$, will by the addition of the products make 240. The plank being thus brought to a state of equilibrium must in order, to make it vibrate, have some impulse given to it by some motion of the children, or by their alternately pressing their feet against the ground.

LECTURE XI.

THE LEVER.

231. Levers are of *three* kinds, according to the *position of the power and weight with respect to the fulcrum.* In the *first* kind

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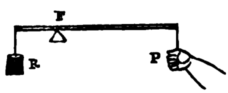
231. Different kinds of levers.

of lever, the *fulcrum is between the power and the weight*; in the *second* kind, the *weight is between the power and fulcrum*; in the *third* kind, the *power is between the weight and fulcrum.*

Levers of the first kind.

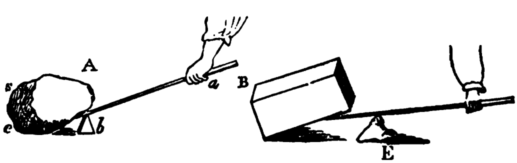
232. In a lever of the *first* kind, the *fulcrum*, F, *is between the power*, P, *and the resistance or weight*, R. A poker used for raising coals in a grate, is an example, the bar of the grate being the fulcrum. The common balance is also a lever of the first kind. But where the fulcrum is equally distant from the two forces, as in the balance, there is no mechanical power, for as the two arms of the lever are equal, nothing is gained by velocity. *False balances* have the arms of the lever unequal in length. Thus a dishonest trader defrauds, both in buying and selling. In *selling*, he puts his goods in the scale, which is suspended to the *longer arm*, and here they appear to weigh more than they do in reality, by balancing a greater weight nearer the fulcrum. In *buying*, he puts the article of merchandize into the scale suspended to the shorter arm, or *nearer to the fulcrum*, where the real weight of the commodity would be balanced by a lighter weight in the other scale. The fraud may be detected by making the weights and merchandize change places. A weight of *one* pound will balance another of *three* pounds, if the *smaller weight be three times farther from the fulcrum than the larger one.*

Fig. 63.



233. If it be required to raise a stone, *s*, (at A) which weighs 1000 pounds, by the strength of a man equal to 100 pounds weight,

Fig. 64.

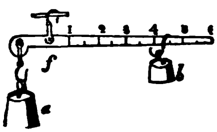


a lever, *a c*, which rests on the prop *b*, should be placed with one end under the stone. As the man's strength is only equal to the tenth part of the weight of the stone, the arm o the lever, *b a*, must be ten times as long as the arm *b c*, in order that the power

232. Lever of the first kind. False balances how contrived.
233. To move a weight of 1000 pounds by a force of 100 pounds

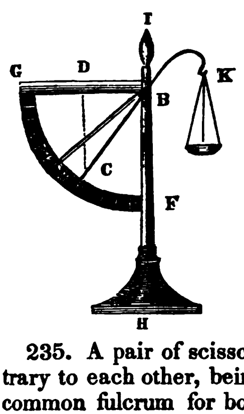
and weight may balance each other. In another case illustrating the same principle, the hand represents the force, raising the heavy weight B, by a lever resting upon the fulcrum E.

Fig. 65.



234. The *steel-yard* is a lever of the first kind, having its arms unequal; and any weight, as *b* on the long arm, will balance as much more weight than *a* on the short arm, as *b* is farther from the fulcrum than *a*. Thus if the hook at the short end, be one inch from the fulcrum *f*, a pound weight *b*, will balance four pounds, *a*, at the short arm. If the article to be weighed be heavier than *b*, or more than one pound, it must be removed farther from the fulcrum in order to find its equipoise against the weight *a:* if lighter than *b*, or less than one pound, it must be nearer the fulcrum. The figures on the long arm of the steel-yard represent pounds, the divisions between them half pounds. Steel-yards are usually marked by notches signifying halves and quarters of a pound; and sometimes by notches representing ounces. A steel-yard has usually two graduated sides, one for smaller, the other for greater weights. On the side for the greater weight, the weight is placed nearer the fulcrum.

Fig. 66.



The *bent lever* balance is represented in the figure. The weight C acts as upon the point D; and the weight in the scale acts at K; hence an equilibrium will take place, when the article weighed bears to C the same ratio as D B to B K. Now every increase of weight added to the scales causes C to rise on the arc F G, and D to recede from B. Hence the different positions of C, according as different weights are added to the scale, may be easily determined, and the corresponding numbers marked on the scale F G.*

235. A pair of scissors is composed of *two levers* acting contrary to each other, being held together by a rivet, which is the common fulcrum for both levers. In using them, the hand is the

* Olmsted.

234. The steel-yard. How can a pound weight be made to balance four pounds? If the weight be greater or less than four pounds. The bent lever balance.

235. Other examples of levers of the first kind.

power, and the article cut, is the resistance. The handles are usually nearest the fulcrum, and are then the short arms of the lever. Materials which are hard to cut, are best operated upon by being placed near the rivet, or fulcrum. In shears used by tinners in clipping tin, the handles are very long, thus giving an increase of power, by bringing the resistance near the fulcrum. Pincers and sugar cutters are also double levers of the first kind.

Fig. 67.

236. Figure 67 shows a long, single lever turning on a strong iron-pin as a fulcrum; the long arm gives a great advantage in raising heavy bodies, as by means of it, a small power acting at A, may overcome a great resistance at B. An ancient philosopher, Archimedes, said, "Give me a lever long enough and a fulcrum strong enough, and with my own weight I will lift the world. But as a power acting by a lever produces a force, greater in proportion as the distance from the fulcrum is greater, because of the greater velocity thus acquired; it follows from mathematical demonstration, the power being compared with the resistance, that the philosopher, if he had been furnished with the *long lever* and strong *fulcrum* which he desired, must have moved with the velocity of a cannon ball for millions of years, in order to have raised the earth the smallest part of an inch. This may be illustrated by a common example, that of prying a nail by means of what is called a claw-hammer, which is a bent lever. Let the handle or shaft of the hammer, be six times as long as the iron part that draws the nail, and which rests against the board, a man will pry up the nail with one sixth part of the power that he must use to pull it out of the board with a pair of pincers. In the latter case, the nail would move as fast as the hand, but in the former case, the hand would move over six times as much space as the nail, by the time the nail is drawn out. That is, the hand moves six inches, in moving the nail one inch.

Levers of the second kind.

237. *In a lever of the second kind, the weight is between the fulcrum and the power*; in this case, *the forces are on the same side*;

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236. Advantage of a long lever. Assertion of Archimedes. Velocity necessary for a man to move the earth with a lever. Illustration.

237. Levers of the second kind. Example. Advantage gained by this lever. Why is this the most efficient kind of lever?

Fig. 68.

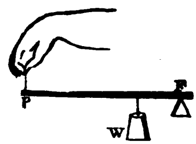
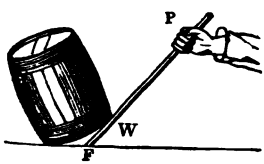


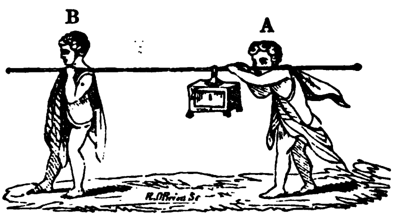
Fig. 69.



the *more distant force acts as the power*, and the nearer, as the weight or resistance. In Fig. 69, a hand-spike is represented as a lever of the second kind; *the ground* F, is the *fulcrum*, the barrel or the *weight* W, is next, and the hand or *power*, at the end opposite the fulcrum. The power, as in levers of the first kind, is at a greater distance from the fulcrum than is the weight, and the *advantage* gained by this lever, is also greater, in proportion as the distance of the power from the fulcrum, exceeds the distance of the weight from the fulcrum. Thus, if P be five times as far from W as is F, then one pound at P will raise six pounds at W.

This is the most efficient kind of lever. The effect produced in the use of levers depends, in part, upon this, whether the power and weight move in *contrary* directions, or in one and the *same* direction. In the use of the lever of the first kind, *the power moves in one direction, while the weight moves in another;* but in the use of the lever of the second kind, both the power and the weight move in one and the *same* direction. P is equal to 1 pound, and F is equal to 5 pounds; the barrel is therefore moved by a force of 6 pounds. If we conceive Fig. 69, to represent a lever of the first kind; then W becomes the fulcrum, and P becomes a *pulling* instead of a *pushing* power, and the weight would be moved at F. Now 1 pound at P would create a pressure *upward* of 5 pounds at F, and a pressure downward of 6 pounds on the fulcrum W.

Fig. 70.



238. Two persons carrying a burden upon a pole, bear shares of the load, in the *inverse proportion of their distances from it;* that is, the one who is nearer to it, bears the greater share; if A be four times as near the load as B, then A will bear four times as much of the weight as B.

239. A door moving on its hinges is a lever of the second kind. The hinges are the fulcrum or center of motion, the door is the weight or resistance, and the hand, in opening and shutting, is the power. Let a person attempt to push open a large heavy door by using his strength near the hinges or ful-

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238. Other examples of levers of this kind. Two persons carrying a weight.
239. *A door, a lever, &c.*

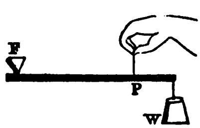
crum, and he will find much force necessary; whereas, by pushing at the part farthest from the hinges, he will move the door with ease. If, while a person is sitting upon a bench near the middle, another should attempt to raise the bench, by one end, the resistance would be much greater than if the person were sitting at the opposite end.

The *oar of a boat*, is also a lever of the second kind; the water being the fulcrum, the boat the resistance, and the hand of the rower, the power. The mast of a vessel, may also serve as an example of a lever, the bottom of a vessel being the fulcrum, the vessel the weight, and the wind the moving power.

The *crane*, a lever of the second kind, is used for transporting great weights a short distance, as heavy boxes of merchandize from a vessel to the wharf. An example of the crane is seen on a small scale in the apparatus of a kitchen fire place.

Levers of the third kind.

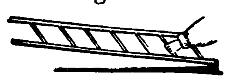
Fig. 71.



240. *In levers of the third kind, the forces, as in those of the second kind, are on the same side, but the power is applied between the weight and the fulcrum.* In a lever of this kind, the power being nearer to the fulcrum than the weight is, the advantage is in favor of the latter; and a greater power would be required to move the weight by means of this lever, than without its aid. But in this case the power will raise the weight through a greater space than that through which the power itself passes, thus giving increased velocity to the weight. This kind of lever is not used to overcome great resistance, but to move a weight with greater speed, or on account of its adaptation to some particular purposes.

241. In *elevating a ladder*, the ladder is first a lever of the second, and afterwards of the third kind. While the center of gravity is between the hands that raise it and the ends on which it rests, the ladder is a lever of the second kind, but when the hands pass the center of gravity, (as is seen in the figure,) the ladder becomes a lever of the third kind. Here the longer part of the ladder, or the resistance, has the same advantage in velocity, which is possessed by the power acting at the long arm of a lever of the first kind. The nearer to the ground or fulcrum of the ladder, the power of the hand is applied, the greater the difficulty in raising the weight. The *shears used for shearing sheep*, are double levers of the third kind; the parts are not connected by a rivet, which forms the fulcrum in common shears, but the power of the hand acts by pressure on a part near the middle; the fulcrum, or sup-

Fig. 72.

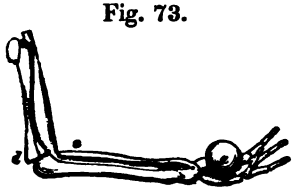


240. Levers of the third kind.
241. Examples of levers of the third kind.

port, being at the end opposite to that in which is the resistance, or the wool to be sheared. The advantage of these shears is, that little force is needed; what the power loses, is gained in the velocity with which the parts next to the resistance act. In using the common *fire tongs*, the ends of the tongs move with much greater velocity than the fingers, and it is only a small weight that we can lift with them, and this weight is less in proportion, as the legs of the tongs are long.

242. The most interesting examples of levers of the third class are to be found in the *bones of animals*, which give rapidity of motion at the expense of power. Here the *bone may be considered the lever, the joint the fulcrum, and the muscles the power.* In the human arm, the elbow *d*, is the center of motion, or fulcrum; at *e*, is the muscle, which acts as the power in raising a weight, *a*; the muscle being about one tenth part as far below the elbow as the hand, it follows that it must exert a power equal to one hundred pounds to raise a weight of ten pounds. By this we see how strong must be the muscles which give power to the animal frame; but this strength seems necessary in the position the muscles occupy, acting, as they do, at the mechanical disadvantage of being so near the fulcrnm. But by this loss of power, much is gained in velocity; and to man, with all his advantages of various mechanical powers for increasing force, it is of great importance that his hands are so supported, that he can move them with quickness, and adapt them readily to a great variety of motions, impelling other forces at his will, and causing them to obey his bidding.

Fig. 73.



Compound Levers.

243. Any number of levers may be connected together, so as to constitute a *system of levers*, the power acting on the end of the first lever raising the end of the second, and that depressing the end of the third so as to raise the weight at the opposite extremity. In this machine, the force is increased in proportion to the number of levers employed. *Ex.* In a compound lever, the lengths of the longer arms are 5, 10, 16 feet, respectively, and of the shorter, 1, 2, 3 feet: what power applied to the longer side, will be required to balance a weight of 100 pounds?

$5\times10\times16 : 1\times2\times3 :: 100$: performing the multiplication indicated, the proportion becomes $800 : 6 :: 100$: multiplying the mean terms of this proportion and dividing by the extreme, we have $100\times6=600\div800$, but as we

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242. Bones of animals examples of levers of the third kind. The human arm.

243. Compound levers.

cannot divide a less number by a greater, we express it in the fractional form $\frac{600}{800}$; reducing this fraction to its lowest terms, it equals $\frac{3}{4}$ the last term, therefore we have

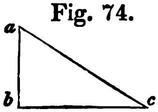
lbs. *lb.*
$5 \times 10 \times 16 : 1 \times 2 \times 3 :: 100 : \frac{3}{4}$ Ans.

LECTURE XII.

THE INCLINED PLANE.

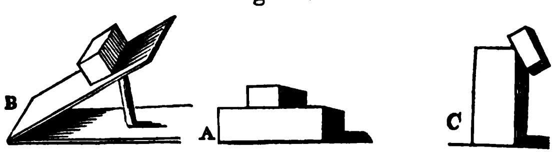
244. The *inclined plane* is the most simple of the mechanical powers. It is used in raising heavy weights. A plank placed in a slanting position for the purpose of rolling up casks into a warehouse, is an example; *a c*, represents an inclined plane, *a b*, its height, *b c*, its base. That a weight could be more easily *rolled up* a slope, than *raised perpendicularly*, is very evident. But the advantage is gained at the *expense of time*, because instead of moving directly from *b* to *a*, the weight moves over the line *a c*; the resistance being less in proportion as the line *a c* is longer than the line *a b*; *therefore, as the length of the plane is to its height*, so is the resistance diminished. In the inclined plane, the power has to overcome only a *portion of gravity at a time*, and this portion is greater or less, as the plane is more or less elevated.

Fig. 74.



245. On a plane, perfectly horizontal, as at A, (Fig. 75,) the pressure of a body is entirely sustained by the plane, and the pressure upon it is *equal to the whole force of gravity*. When one end of the plane is elevated, as at B, *the force of gravity is resolved into two forces, the one acting parallel to the plane, and the other acting perpen-*

Fig. 75.



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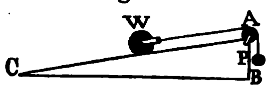
244. Inclined plane. Advantage gained at the expense of time. By what rule is the advantage of the inclined plane estimated?

245. In what case is the pressure on a plane equal to the whole force of gravity? What is the effect of inclining this plane in respect to gravity? Of raising the plane perpendicularly?

dicular to it. In proportion as the plane is more elevated, that part of the force of gravity which acts in a line with it is increased; and when the plane is raised perpendicularly as at C, the whole force of gravity acting in one direction, causes the body to offer an undivided resistance to the power which should attempt to support it.

246. *The power applied in raising a weight upon an inclined plane, must be to the weight, as the height of the plane is to its length.*

Fig. 76.



Suppose the perpendicular *height* A B, to be *one foot*, and the *inclined surface* A C to be *four feet;* then a *weight* W, of *four pounds, resting on the plane, will balance one pound* P, acting over a pulley; that is, one fourth of the weight necessary to lift a weight through the space A B, the vertical height, would be sufficient to force it up the inclined plane, from C to A. Here it will be seen, that what is gained by power is lost in time, which is the case with all kinds of machines. From the simple nature of the inclined plane, it is probable that it was used in remote periods of antiquity. The Egyptians are supposed to have made use of very long inclined planes in elevating the huge masses of stone which form the pyramids.

247. Roads over declivities are inclined planes. A horse in drawing a load over level ground, meets with no resistance from gravity; he *drags* but does not *lift* the weight, that is, the resistance is from *friction*, which being proportioned to weight, is of course greater with a heavy than with a light load. But in drawing the load up a hill, the horse has to overcome more or less of the force of gravity; that is, he *lifts* a part of the load, and this part *is greater, in proportion to the steepness of the ascent;* or, in other words, he lifts such a part of the weight, as bears to the whole weight, the proportion, that the perpendicular height of the hill bears to its length. If, in a length of *ten feet*, there is a rise of *one foot*, the horse lifts *a tenth* of the load. In constructing roads, there has been, in our country, a great disregard of mechanical principles. The desire of "going straight ahead," has led road-surveyors to go up and down hills, when, by going round their bases, they would have an equal distance over a level road. Railroads are constructed on the principle of the inclined plane. They are made either level, or with so gradual a slope, that the drawing horse,

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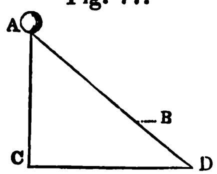
246. Rule with respect to the power needed to raise a weight on an inclined plane. Examples.

247. Roads. What is to be overcome in drawing a load on level ground? What in drawing a load up hill? Should roads be made to go over, or around a hill?

or steam engine, has little more than the friction of the carriage to overcome. By means of railroads, the hills and valleys of an uneven country are reduced to horizontal and inclined planes. In passing considerable elevations, it is, sometimes necessary that the inclined planes should be very steep; in which case, cars are drawn up by means of a steam engine stationed on the summit; and sometimes cars descending on one side, are made to draw up others on the other side, the two being connected by a rope passing round a pulley on the summit.

248. *Bodies descending freely down inclined planes move with uniformly accelerated velocity*, but this velocity is not so great as in falling through an equal space in a perpendicular direction. Thus, supposing the distance from A to B, to be equal to that from A to C, and the former an inclined plane, the latter perpendicular; a ball falling from A to C, would acquire greater velocity, than in rolling down the inclined plane to B; but let the ball move from A to D at the base of the plane, and its velocity will be equal to that gained by falling from A to C. Rule—*the velocity acquired in falling from an inclined plane is equal to that acquired in falling through the perpendicular height of the same plane.*

Fig. 77.



Compound Mechanical Powers.

249. The three mechanical powers, viz., the *cord, lever, and inclined plane*, appear under the different modifications of the *wheel and axle*, the *pulley*, the *wedge*, and the *screw*. The *wheel and axle* is a variety of the lever, both machines being regulated by the same principle. The *pulley* depends for its utility upon the cord, though as it is used with wheels, it partakes of the nature of the lever. The *wedge* is a double inclined plane, acting on the same principle as the single inclined plane, but with twice the effect. The *screw*, which is a modification of the inclined plane, operates through the aid of the lever.

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248. Velocity of bodies moving freely down an inclined plane. Rule
249. Different modifications of the mechanical powers.

LECTURE XIII.

THE PULLEY.

250. *The cord is the essential part of the pulley*, but it cannot be used to advantage without a wheel. If a rope were perfectly flexible, it might be bent over any sharp edge, and thus enable force to overcome resistance, or to communicate motion in any desired direction.

251. Suppose P to be a sharp edge, with a rope passing over it; a sufficient force F, acting in the direction F P, would overcome the resistance R, and produce motion in the line R P. But as no materials of which ropes are made, can be perfectly flexible, and as they are rigid in proportion to their strength or ability to transmit force; cords could not be applied to machinery, except some means had been devised to overcome these obstacles. If a cord were to be used to transmit a force from one direction to another, it would require some force to bend it over the angle P, and this by its sharpness, would soon break the cord.

Fig. 78.

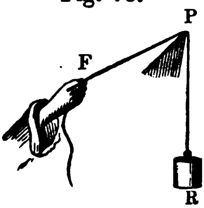
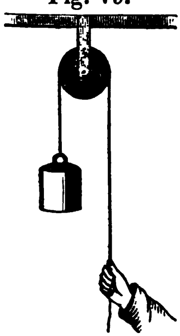


Fig. 79.



252. By bending a cord over the surface of a *curve*, it may be made to sustain a certain weight, but when motion is to be produced, the rope in passing over the curve would meet with much resistance from friction. But in the pulley, the curved surface moves with the rope, and thus is obviated the difficulty which, otherwise, would attend the use of this mechanical power.

253. *The wheel of the pulley is called a sheave; this is fixed in a block and turns upon a pivot.* In the edge of the wheel is a *groove*, made for the rope to move in; the wheel itself revolves on the pivot, which is its axis of motion. The figure represents what is called a *fixed pulley.*

254. The fixed pulley gives no mechanical advantage, but its

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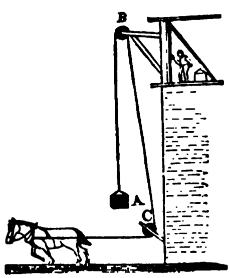
250. Essential part of the pulley.
251. Cord passing over an edge or angle.
252. Curved surface of the pulley.
253. Wheel or sheave of the pulley.
254. Use of the fixed pulley.

chief use is to *change the direction of forces.* This, however renders it of great importance, since in the application of power, whether of men or animals, there are always some directions which are more convenient and advantageous than others. A machine, therefore, which gives man the ability thus to transmit or change the direction of moving powers, is not less important than one which enables him with the aid of a small power to overcome a great weight.

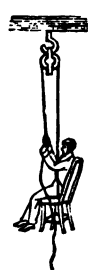
255. It would be very inconvenient to climb up, in order to roll a curtain; but by means of the pulley, the object is effected by the mere drawing down of a cord. It is also much easier to raise a bucket from a well, by means of drawing downwards upon a rope fixed to a pulley, than to lift the weight by pulling it upwards. Boxes, bales of goods, and casks, are raised, by pulleys, to the upper lofts of stores, and huge masses of stone, to the fourth and fifth stories of buildings. By means of the pulley which is used in hoisting sails and weighing heavy anchors, a smaller number of seamen than would otherwise be required, are enabled to manage a ship.

Fig. 80.



256. The better to adapt the power to the resistance, two pulleys are often used. The strength of a horse may be so directed as to carry heavy loads to great perpendicular heights. Thus suppose B and C two fixed pulleys, and A, a block of marble fastened to a rope, which being carried over the pulley B, passes round C, and in the horizontal direction thus given, is drawn by the horse to which it is fastened. Every step of the animal causes an ascent of the stone, until arriving at the pulley B, it is applied to its destined use by the workmen at the top of the building.

Fig. 81.



257. By means of the fixed pulley fastened near the window of an upper story, a man might let himself down, to escape from fire, when other means were wanting; and, by the same means, a person might draw himself up from a well or mine. But an attempt of this kind would be dangerous, except in the case of one having great muscular strength in proportion to his weight.

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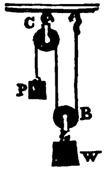
255. Applications of the pulley.
256. Why are two pulleys sometimes used?
257. Descending and ascending by means of a fixed pulley. Is there any increase of power gained by the fixed pulley?

258. ***The movable pulley gives to the power a double advantage over the weight.*** B represents a movable pulley, in connection with a fixed pulley C. The weight W, is attached to the movable pulley, and as it bears equally upon the two parts of the rope which pass round the pulley B, the power P having only to resist the force B C, has to sustain but half the weight in order to balance W. Therefore, *when the power is equal to half the weight, an equilibrium is maintained.* If the weight is 12 pounds, it will be balanced by a power equal to 6 pounds; but for every inch that the weight is raised, the rope must be drawn at P two inches. With the movable pulley, a man raises twelve pounds with the exertion of only so much strength, as would, otherwise, be required to raise six pounds: but, in order to do this, his hands move through a space of *two feet,* whereas, if he lifted the whole weight, they would only move through a space of one foot. Thus the advantage gained, is in proportion to the space passed through. It is, as if the weight were divided into two equal parts, and raised successively. In the movable pulley, as in the lever, the deficiency in the power is compensated by greater velocity.

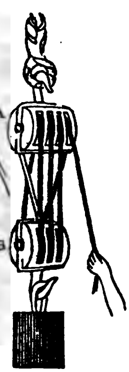
Fig. 82.



259. *Compound pulleys* are combinations of many pulleys, in which the weight is distributed over a greater number of parts of the rope, each part, consequently, sustaining a smaller portion of the weight. As the hands move over *twice the space* for every pulley, it follows that *two acting pulleys, increase the power four times, three acting pulleys, six times,* &c.

Fig. 83.

Fig. 84.



260. Fig. 83 represents a system of pulleys called a *tackle,* having the rope successively passed over the pulleys above and below, until after passing over the fixed pulley A, it is attached to the power. *The weight is as many times greater than the power, as is the number of the folds of cord.* Fig. 84 represents a tackle having the pulleys arranged side by side, in two blocks placed, the one above another. In the upper block there is an addition-

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258. Advantage of the movable pulley.
259. Compound pulleys.
260. How may a weight of 72 pounds be held in equilibrium by a power of 9 pounds?

al wheel or pulley, which adds 1 to the power of the machine.

By means of four movable pulleys, a weight of 72 pounds may be held in equilibrium by a power of 9 pounds; dividing the weight by 8 the folds of cord, we have the quotient, 9. But the power, when in motion, must pass over *eight* times as much space as the weight; therefore *what is gained in power is lost in time.*

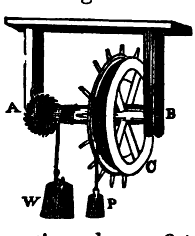
261. Owing to the *friction of the wheels and blocks* and the *stiffness of ropes*, all the advantage which in theory is stated as being gained from the use of blocks of pulleys, is not realized. The weight of the several parts in the machinery is also to be considered, in estimating the advantage of this mechanical power.

LECTURE XIV.

THE WHEEL AND AXLE.—THE WEDGE.—THE SCREW.

262. The wheel and axle, is a wheel turning round, together with its axis.—The *power* is applied to the circumference of the wheel, and the *weight* to that of the axis, by means of cords. Let A B represent an axle, turning upon pivots at its extremities, and having a rope coiled around it, which sustains the weight W. Around the wheel C, which is fixed to the axle, a rope is coiled in a contrary direction from that around the axle, and supports the power P. In turning together, the wheel will take up, or throw off, as much more rope than the axle, as its circumference is greater than that of the axle. If the proportions be as 6 to 1, one pound at P will balance six pounds at W.

Fig. 85.



263. The wheel and axle is considered as a lever of the first

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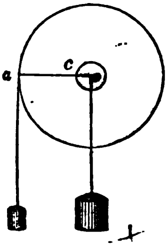
261. Effects of friction, and of the stiffness of ropes.
262. How is the power applied to the wheel and axle?
263. Describe the operation of the wheel and axle.

Fig. 86.



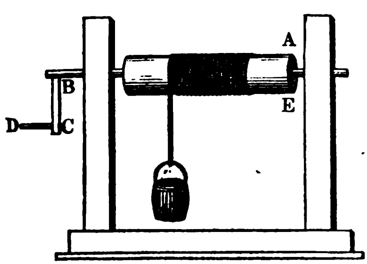
kind, in which *c*, the center of the axle, represents the fulcrum; the radius of the wheel the longer arm of the lever; and the radius of the axle the shorter arm. *Therefore, the power and weight are in equilibrium, when the power bears the same proportion to the weight, as the radius of the axle c o, bears to the radius of the wheel a o.* Thus if the diameter of the wheel is ten times that of the axle, a power of one pound will balance a weight of ten pounds.

264. Since the wheel and axle are shown to be of the same nature as the lever, the inquiry may naturally arise, "wherein consists the advantage of the former over the latter?" When a lever is used for raising a weight, it can act but through a small space at a time; but, from its simplicity, the lever is of great use in raising heavy weights through a short space. When a *continuous motion* is to be produced, as in drawing water from a well, raising ore from a mine, &c., some contrivance is necessary to render the action of the lever continuous; the spokes or radii of the wheel and axle acting as so many levers, and revolving regularly and without intermission, produce this desired effect.

265. Although the axle is usually nothing but a cylinder fixed upon pivots, yet, as it revolves about these as a center of motion, it is, in effect, a wheel; and half its diameter or one of its radii, bears the same proportion to the whole circumference of the axle, as a spoke of a wheel to the circumference of the wheel.

266. In the common *windlass*, used in drawing water, what is called the *crank* or winch B C, serves the same purpose as a wheel, being the radius or half the circumference; D is the handle by which the power is applied. At each revolution of the crank, a circle is described; and the effect of the revolution upon the axle is the same as if the wheel were entire. Therefore it follows, that as B C represents the spoke of a

Fig. 87.



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264. Wheel and axle considered as a lever. Rule. Advantage of the wheel and axle compared with that of the lever.

265. How may the axle be considered a wheel?

266. Describe the common windlass.

wheel, or the radius of a circle, the power will be increased, in proportion as the circle described by B C, is larger than the circumference of the axle, A E.

267. The *capstan* used in ships and dock-yards, for weighing heavy anchors or drawing vessels into harbor, is one of the most useful applications of the wheel and axle. In this, the axle is vertical; its circumference, near the top, is pierced with holes, into which, when the machine is to be worked, are inserted long levers, called *capstan bars*. These answer the same purpose as the spokes of a wheel, or the crank of a windlass. The men who work the capstan walk around the axle, pressing the bars forward, and the cable is thus wound about the axle with a force sufficient to lift a heavy anchor, or draw a large ship into harbor.

Fig. 88.

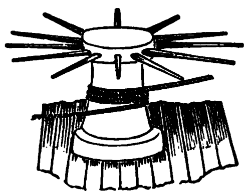
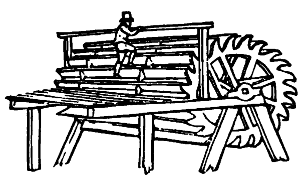


Fig. 89.



268. The treadmill, is turned by the weight of men, who step forward as fast as the wheel descends, thus maintaining their position at the extremity of the horizontal diameter of the wheel. Horses may be made to work the machinery of a mill, when harnessed to the extremities of shafts or long levers fixed to an axle, which they turn by walking in a circle; examples of this may be seen in cider-mills, brick-yards, &c. The horse-boats used in crossing ferries, are moved by the stepping of the animal upon a horizontal wheel connected with paddles, or, with a perpendicular wheel.

Compound Wheel and Axle.

269. *In the compound wheel and axle, the power is to the weight, as the product of the diameters of all the smaller wheels, is to the product of the diameters of all the larger wheels.* Thus the power being applied to the winch P Q, acts upon the small wheel A, which acts upon the large wheel B, this upon C, and this again upon D, which exerts its original and accumulated power upon

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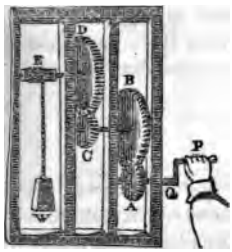
267. What is a capstan?
268. Tread-mill. Mills and boats moved by horses.
269. Relations of the power and weight in the compound wheel and axle. *Rule to be* applied to the action of the compound wheel and axle.

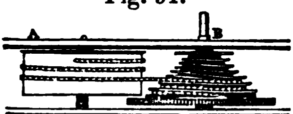
Fig. 90.



the axle E, which supports the weight W. Now, if the diameters of the three smaller wheels, including that of the axle, be severally, one fourth those of the larger wheels, (of which the diameter of the wheel described by the winch P Q, that is twice P Q, must be considered as one) then the power will be to the weight as $1\times1\times1 : 4\times4\times4$, that is as 1 to 64; and a force of ten pounds applied at P, will balance a weight of 640 pounds applied at W; or in other words, if one pound will balance 64 pounds, ten pounds will balance 640.

270. "It is, sometimes, desirable to make a *variable power* produce a constant force. This may be done *by making its velocity increase, as its intensity diminishes.* We have an example of this in the *reciprocal action* between the *main-spring* and *fusee* of a watch. The *main-spring* is coiled up in a box A, and is connected with the fusee B, by a chain. When the watch is first wound up, the spring acts with its greatest intensity, but then as the wheel B turns, it uncoils with the least velocity; but on account of the varying diameters of the wheels of the fusee, the velocity is continually increased, as the intensity of the spring is diminished."*

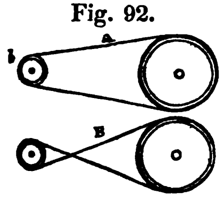
Fig. 91.



One turn of the axle on which the watch key acts, is, by the train of wheels attached to it, rendered equivalent to about four hundred beats of the balance wheel, and thus the exertion during a few seconds, of the hand, in winding up a watch, produces motion for twenty-four hours, or more.

271. Wheels may be connected by bands, as in the turning-lathe, and the common spinning-wheel. A spinning-wheel, as A of thirty inches in circumference, turns, by its band, a spindle of half an inch, *b*, sixty times, for every turn of itself. If the wheels connected by bands are required to revolve in the same direction, the bands are arranged as at A; but if they are required to revolve in different directions, they are arranged as at B, where the band is crossed.

Fig. 92.



* Olmsted.

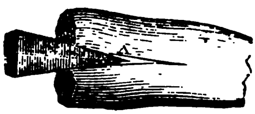
270. Constant force produced by a variable power. Example.
271. Wheels connected by bands. Cross-band.

In *spinning*, the band of the wheel is fixed as at A; but in *twisting two or more threads together*, the band of the wheel is crossed as at B. Two persons standing opposite and facing each other, in twisting a string, the fingers of each having the same motion, will produce a twist like that made with the cross-banded wheel.

The Wedge.

272. *The wedge may be considered as two inclined planes, whose bases are joined.* The wedge is forced in between resistances to separate them, instead of having the resistance moved over its surface as in the inclined plane. The more acute the angle A, at the extremity of the wedge, the greater its power is estimated to be. But the wedge is used in such a manner that, it is difficult to compute its actual power, as this must depend greatly on the strength of the blow with which it is forced against a resistance.

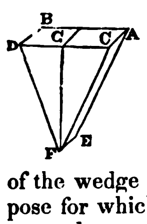
Fig. 93.



In splitting logs of wood, and masses of stone, this mechanical power possesses a peculiar advantage, for, by its means, a great force can be exerted through a small space.

273. A wedge is of that form, known in geometry, as a *triangular prism.* Suppose the edge, or angle E F, impelled against a block of wood, by a force applied at the surface, A B D C, the effect of this force will be in the ratio of the line D F, to the line G D, or, as the sides of the wedge are, to half its breadth. That is, the power is increased, either by diminishing the back of the wedge, or by increasing its length. Sharp edged, and sharp pointed instruments act on the same principle as the wedge; as the axe, chisel, knife, pin, needle, and shoemaker's awl. The angle of the wedge is rendered more or less acute, according to the purpose for which it is to be applied. In determining this, two things are to be considered; the mechanical power, which is increased by diminishing the angle of the wedge; and the strength of the tool, which is also diminished by the same cause. There is, therefore,

Fig. 94.



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272. Wedge, and manner of its use described.

273. Advantage of the wedge. Geometrical form of the wedge. Instruments which act on the principle of the wedge. What two things are to be considered in determining the acuteness of the wedge? What tools may be *made most acute?*

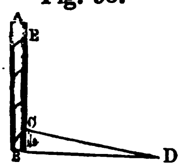
a limit beyond which the sharpness of the instrument would destroy the requisite strength.

Tools which act by pressure may be made more acute than those which act by the force of a blow; and the softer, and more yielding, the substance to be penetrated, the less is the power required to act upon it, and the more acute the wedge may be made. Thus a cambric needle, and lancet, are manufactured in reference to the materials they are designed to work upon. An axe, for cutting wood, is more acute than a wedge for splitting iron.

The Screw.

274. *The screw* is a modification of an inclined plane. A straight road from the top, to the bottom of a high hill is, evidently, an inclined plane. If, instead of going directly up the hill, the road wound around it, in a spiral manner, it would still possess the essential characters of an inclined plane. The screw may be considered a *winding wedge*, bearing the same relation to a straight wedge, that a road winding up a hill, bears to a straight road up the same hill. Let A B, represent a common round ruler, having a paper cut in the form of an inclined plane wound around it, the edge of the paper E C D, being marked by a black line: the ruler will then present the appearance of a screw, the line E C D, representing what is called the *thread of the screw.*

Fig. 95.



275. The advantage gained by the screw, depends much upon the *slowness of the ascent,* that is, upon the number of turns or threads in a given distance.

The screw consists of two parts, a solid cylinder, around which passes spirally the *thread* of the screw, and a hollow screw, with a similar thread, winding without it, exactly adapted to the interval between the turns of the thread of the solid screw; and thus, either part being made to revolve, while the other is kept firm, pressure to almost any extent may be produced. The screw is generally used with a lever, which assists in turning it; with this addition, it is a machine of great force, either in compressing bodies, or in raising great weights. It is to this mechanical power, that we are indebted for the common printing-press, and for most of the presses which are used in the arts and manufactures.

276. L, represents the *lever* attached to the solid cylinder.

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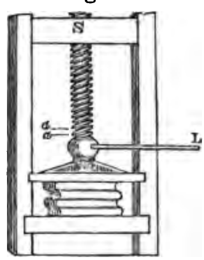
274. Of what is the screw a modification?

275. On what depends much of the advantage gained by the screw? Of what parts does the screw consist? Use of the lever combined with the screw.

276. Describe the screw. On what does the power of the screw depend?

Fig. 96.



The cylinder in ascending or descending the hollow screw, travels in a spiral line. *The closer the threads of the screw, the greater the power of the instrument;* though, as more time is then required to traverse it, we find that here, as in the other mechanical powers, *what is gained in power is lost in time.*

277. *The screw acts with the combined power of the lever and the screw.* The power of the screw is also affected by the length of the lever which turns it; for the greater the circumference which the lever describes in one revolution, the more powerful is the action of the screw. In calculating the effects of the screw, the proportion should be estimated *between the space described by the power in one revolution of the screw, and the space between any two of its contiguous threads.* Thus, if the threads, *a a,* (Fig. 96,) be *half an inch* apart, and the screw be turned by means of the lever L, extending *three feet* from the center of the screw; the advantage of such a machine will be, as the number of *half inches* in the space described by the extremity of the lever, are to unity or 1. Now reckoning the circumference of a circle to be three times its diameter, the circumference described with a radius of three feet (because there are thirty-six inches in three feet) will be $36 \times 2^* = 72 \times 3 = 216$ inches; and twice that number, or 432 to 1, will be the measure of advantage afforded by the machine.

278. It might be inferred that the power of the screw acted on by the lever could be indefinitely increased by extending the length of the lever, or by diminishing the interval between the threads of the screw. But a very long lever would be inconvenient, and extremely thin threads would be broken by the pressure when any considerable force should be applied to turn the screw; so, that beyond certain limits, the lever cannot be lengthened, nor the distance between the threads of the screw shortened.

Hunter's compound screw increases the efficiency of the power 5040 times. The *micrometer screw* by the fineness of its threads, combined with other mechanical advantages, affords the means for measuring the fibre of a spider's web, the size of microscopic insects, or other objects too minute to be perceived by the naked eye. It has been adapted to the microscope.

279. The ancients understood the use of complicated machinery. Plu-

* The radius is *half* the diameter of a circle; therefore 36 multiplied by 2 makes the whole diameter 72 inches;—this being multiplied by 3, shows the circumference to be 216 inches.

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277. How does the length of the lever affect the power of the screw? How is the power of the screw estimated?

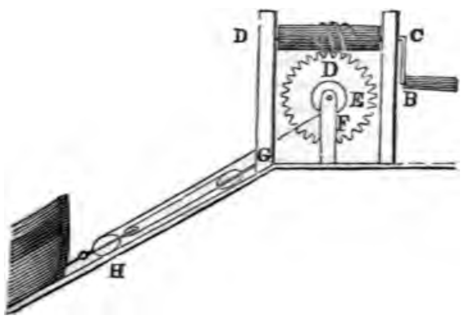
278. Can the power of the screw be indefinitely increased? Hunter's screw. Micrometer screw.

279. Use of complicated machinery by Archimedes. Describe the machine in which five mechanical powers are introduced.

tarch states that Hiero, king of Syracuse, was greatly astonished at seeing the philosopher Archimedes, sitting on the sea shore and drawing into port, with one hand, a large ship, heavily laden. According to the historian, this was done by gently moving the handle of a machine called *polyspaston*, or pulley.

"The figure represents *five mechanical powers* combined to form a machine for drawing a ship upon the stocks to be repaired.

Fig. 97.



The handle of the winch BC=18 inches.
The distance of the threads on CD=1 inch.
The diameter of the wheel ED=4 feet.
The diameter of the axle EF=1 foot.
G is a fixed, and H a movable pulley, the number of strings=4.
Height of the plane equals half its length.
Allowing a man to turn on the handle B with a power equal to 100 lbs., how much force could he exert on the ship?

By rule given, 100 lbs. exerted at B would become, at D,.... ×11309.76

And since the diameter of the wheels is four times that of the axle, ×4

45239.04

Again, this is rendered four-fold by the four strings of the pulley,

180956.16

Finally, this is doubled by the plane, 2

361912.32

Hence, the force exerted on the ship would amount to more than 361912 lbs., or more than 161½ tons."*

LECTURE XV.

FRICTION.—MOVING POWERS.—GENERAL REMARKS UPON MACHINERY.

280. *Friction* is that resistance to a moving body which is caused by inequalities of surface. No substance is perfectly smooth; surfaces which appear so to the naked eye, as polished

* Olmsted.

280. What is friction? Are any substances perfectly smooth?

steel or glass, are found, when examined with a microscope, to be rough and uneven, like the face of a file. When substances move in contact, the prominence of one passing into the depressions of the other, occasion more or less resistance to motion.

281. Friction *wears* upon the surface of bodies constantly in motion, and thus, in process of time render the various parts of machines unfit for use. *Cohesive attraction* between substances in contact, is another impediment to motion, though not equal to that caused by the ordinary inequalities of surface. Friction is diminished by making smooth the surfaces which are to come in contact; but this must be done within certain limits, for great smoothness brings the bodies into such close contact as to produce a considerable degree of cohesion. Less friction is produced when the substances which rub against each other are of different kinds, than when of the same kind; as copper slides over brass more easily than over copper. Axles of steel are thus made to revolve on brass; and in watches, the steel axles are often made to play in diamond, or some very hard mineral. The skater, with his steel skates, moves more rapidly over ice, than he could move over polished steel.

By covering the rubbing surface with oil, tar, or soap, friction is diminished. The axles of carriage and spinning wheels, and machines of all kinds, require the frequent application of these lubricating substances.

282. The friction between rolling bodies is much less, than between those that drag. In certain kinds of wheel-work, the axle is made to revolve on small wheels, called *friction-rollers*. *Sleighs* are made to move on runners of steel, which slide over snow paths with little friction. In descending steep hills, it is common for drivers of carriages to *lock* the wheels, thus changing the *rolling* to the *dragging* motion. By increasing friction, the velocity of the descent is impeded.*

283. Friction is proportioned to the *quantity of matter* in a moving body, and not to *the extent of surface*. Thus a brick with sides of unequal width, is found to meet with no greater resistance

* The traveller on the "National road" over the Alleghany mountains, may observe the "breaks" affixed to the stage coaches to produce the effect described.

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281. Effect of friction upon machines. Cohesive attraction impedes motion. How may friction be diminished? Friction less when the substances are of different kinds, than when of the same kind. Examples. Oil, &c., used to diminish friction.

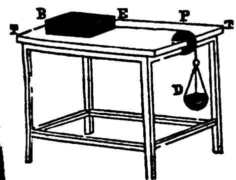
282. Difference in the degree of friction between rolling and dragging bodies. Friction rollers. Increase of friction impedes velocity

283. Friction proportioned to the quantity of matter. Example.

from friction, when moving on the broader, than when on the narrower side. If the *pressure* be increased by laying weights upon the brick, the amount of friction will also be increased, and in an equal proportion to the increase of weight.

284. The *degree of friction* in moving bodies, may be ascertained as follows; suppose a box, B E, to be laid upon a table, T T. Let a silken cord, fastened to the bottom of the box, be carried over the table and pulley at P, the scale, D, being suspended by the cord. If no resistance were offered to motion, it is evident that the smallest weight, attached to the cord, would draw the box towards P. But the friction which always exists, prevents a small weight from drawing the box at all. But let weights be put in the scale D, until a sufficient force is obtained to overcome the friction without giving the box an accelerated motion; such a weight is equivalent to the amount of friction. Now let the weight of the box, (which is supposed to have been previously ascertained) be doubled, by placing in it additional weights, the pressure will be doubled; and it will be found that the weight of the scale D, and its load, which was before able to overcome the friction, is now inadequate to this effect. Let additional weights be placed in the scale until the friction is counteracted as before, and it will be found that the whole weight necessary, for this is exactly twice the weight which produced it in the former case. Thus it appears that a double amount of pressure produces a double amount of friction.

Fig. 98.



285. When a heavy body is placed on an inclined plane it will have a tendency to slide; and will, therefore, remain at rest on such a plane, only when the retarding cause of friction is greater than the tendency for motion caused by the inclination of the plane. The angle of inclination at which motion on an inclined plane commences, is called the *angle of friction;* and, sometimes, the *angle of repose.*

286. Friction may be considered a *passive force.* Its effects on machines in a state of equilibrium, are very different from the effects of the same force on machines in motion. In the one case, friction *assists the power*, in the other case, it *opposes* it. Thus a weight placed on an inclined plane, will require a less power to support it, in consequence of the friction of the two substances; and a weight suspended by a rope passing over a pulley, will require a less weight to balance it, on account of the friction of the axle. But the case is reversed when a machine is to be put in motion; for then, friction makes a still greater power necessary than would overcome the weight, itself. The amount of friction varies in the several mechanical powers; in the lever it is very

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284. How may the degree of friction in moving bodies be ascertained?
285. A heavy body on an inclined plane. The angle of friction, &c.
286. The effect of friction on machines at rest and in motion. Friction varies in the different mechanical powers.

little. In the wheel and axle, the friction of the wheel is in proportion to the weight, velocity, and diameter of the axle; for, the smaller the diameter of the axle, the less will be the friction. In the pulley, wedge, and screw, the friction is great.

287. Notwithstanding the inconveniences of friction in retarding the motions of machinery, it is of great utility. If all bodies were destitute of friction, it would be difficult for us to grasp, or retain in our hands, any solid substance. A knife, a pen, or a book, could not be held without such an exertion of muscular power as would be fatiguing. Without friction, it would be still more difficult to use our feet than our hands; the pavement, or ground, would be more slippery than ice; and if shoes offered no resistance by friction, we should find it difficult to stand still, and much more so to walk.

Friction offers an advantage in *rubbing*, *scouring*, *polishing*, and *grinding*.

288. Besides the mechanical powers which we have enumerated, there are other means of varying and accumulating force which might be considered as mechanical powers. Of these, are *hammers*, *threshing-flails*, *clubs*, *slings*, &c., which enable a *continued moderate effort to overcome a great resistance.*

Moving Powers.

289. In *liquids*, and *aeriform bodies*, we find some of the most effective powers for *moving machinery*. The mechanical powers are of inestimable advantage to man, in enabling him to accommodate the various forces of nature to the work which he has to perform. Thus he makes the *running stream*, the *water-fall*, the *wind*, and *steam*, turn his mills, impel his vessels, and even carry him over the ground, whither he would go. The heavy mill-stone is turned, and the most delicate fibers of cotton and silk are twisted, by these inanimate agents, which man has pressed into his service.

Gravitation, or weight, affords the means of originating motion for many important purposes. By the proper application of this power, is maintained the regular motion of wheel work, as in a common clock, where the downward pressure of the weights keeps the machinery in motion. *Elasticity* gives force to various mechanical agents. Elastic metals, such as steel, manufactured into *springs*, form the moving power in watches and various other kinds

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287. Utility of friction. Examples.

288. Other means of varying and accumulating force. Examples.

289. Liquids and aeriform bodies are moving forces. Examples. Motion obtained by gravitation, elasticity and heat.

of machinery. *Heat*, from its tendency to expand bodies, may be ranked among the moving powers.

290. The application of the natural strength of man, must have preceded the employment of all other moving powers; but the force of brute animals was, by man, early made subservient to his convenience. Oxen and horses appear to have been employed in the labors of the field, in the most remote periods of antiquity; and the ass, camel, and elephant, are mentioned in the Scriptures and in other ancient records as beasts of burden. The mechanical effects produced by the *muscular exertions of living beings* cannot be estimated with the same precision as those of other moving powers, such as steam, water, gravitation, &c. The force of human exertion differs according to the manner in which it is applied. It has been estimated by some ingenious experiments, that the labor of a man employed in working a pump, turning a crank, ringing a bell, and rowing a boat, might be estimated respectively, by the numbers 100, 167, 227, and 248. From this it appears, that in working a pump the man labors to the least advantage; and that rowing a boat is the most advantageous mode of applying human strength. The strength of a horse, in any given time is reckoned equal to that of five men. The strength of the elephant is computed to be equivalent to that of six horses. He will carry 3000 or 4000 pounds, and move at the rate of a slow trotting horse, traveling with ease 40 or 50 miles in a day.

General Remarks upon Machinery.

291. From what has now been learned, with respect to mechanical powers, the student will be prepared to understand some general principles relating to their use. These powers do not, in many cases, *save labor*, but they *enable one man by working longer, to do what many men might perform in a short time.* Thus, by means of a tackle, having ten folds of rope, one man may raise a weight which it would require ten men to raise without pulleys. But if the weight is to be raised a yard, ten men might raise it by pulling at a single rope and walking one yard, while the one man at the tackles, must walk ten yards. Therefore, to accomplish the same amount of labor, we have, in the one case, the time and strength of one man for ten minutes, while in the other, would be required the time and strength of ten men for one minute. A

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290. The strength of man and brute animals. Animal strength not so uniform and precise as other moving powers. The efficacy of human strength depends on the manner of its application. Examples.

291. Mechanical power enables one man to do the labor of many. Examples

printer with his screw, may press a sheet of paper against types, so as to take off a clear impression, whereas, without the press, the strength of fifty men would scarcely be sufficient; and these fifty men would be idle and superfluous, except just at the time when the press-work is to be done. The screw may therefore be said to do the work of fifty men, since it saves the expense of keeping this number to perform what one man can now do.

292. Machinery often enables a man to exert his whole strength, when without this assistance, he could employ but a part of it. Thus, in winding thread, he can turn one spool with one fiftieth part of the force which he is capable of exerting; while, by means of machinery, he may turn fifty spools, in the same time, though with an increased amount of exertion.

Females are greatly indebted to science for labor-saving machines of various kinds. The carding machine has superseded the tedious and laborious use of hand-cards, giving the wives and daughters of farmers not only an exemption from severe toil, but more leisure for mental improvement.

There is also an improvement in the common spinning wheel. An additional small wheel, and short band near the spindle, so much increases the velocity of the motion which twists the thread, as greatly to facilitate the operation of spinning by hand. But carding, spinning, and weaving, are now mostly performed through the agency of complicated machinery, moved by water or steam. The tending of these machines affords support to vast numbers of individuals. A wonderfully increased value is hereby given to human exertions.

293. *Machinery is useful in changing the direction of motion.* The two varieties of motion most common in Mechanics, are the *rectilinear* and *circular.* In rectilinear motion, the several parts of a moving body proceed in *parallel straight lines* with the same speed. In circular motion, the several parts *revolve round on axis,* each performing a complete circle, or similar parts of a circle, in the same time. Each of these two kinds of motion may be either *continued* or *reciprocating.* In a continued motion, the parts *move constantly in the same direction.* In reciprocating motion, the parts *move alternately in opposite directions.*

Continued rectilinear motion, is seen in the flowing of a river, the blowing of wind, the motion of an animal upon a straight road, and in the perpendicular fall of bodies. *Reciprocating rectilinear*

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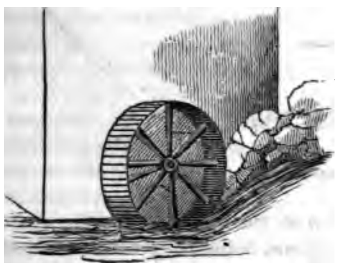
292. A man's whole strength brought into use by machinery. The carding machine. The double wheel-head. Carding, spinning, and weaving by machinery.

293. Difference between rectilinear and circular motion. Continued and reciprocating motion. Continued rectilinear motion. Reciprocating rectilinear motion. Continued circular motion. Reciprocating circular motion.

motion is seen in the rod of a common pump, as it rises and falls, and in the piston of a steam engine. *Continued circular motion* is seen in the revolving of wheels of all kinds, and in turning a crank as in the windlass used for drawing water. *Reciprocating circular motion*, is seen in the pendulum of a clock, and the balance wheel of a watch.

Fig. 99.



294. By means of machinery, a power having any one of these four varieties of motion, may be made to communicate, either the same kind of motion changed in its velocity or direction, or either of the other kinds of motion which we have enumerated.

Rectilinear motion changed to circular.—The continued rectilinear, or straight forward motion of water, produces the circular motion of the *water wheel.*

Fig. 100.

The straight, downward pressure of the foot upon a board communicating by a crank with the common *spinning wheel*, causes its rotary motion. The *turning lathe* of the carpenter, is also an instance of straight motion changed into circular. The alternate rising and falling of the *piston of a steam engine* by means of a crank, communicates motion to the wheels.

295. *Circular motion changed to rectilinear.* The turning of an axle will wind up a rope, and thus lift a weight in a straight line. In the screw, the lever, which has a continued circular motion, causes the screw to advance with a continued rectilinear motion.

296. Machines of different kinds are in use in every family, as the churn, washing machine, apple-paring machine, coffee mill, and clock; while every town and village, has its grist mills, saw mills, and carding machines: and no one can go far in any section of our country, without hearing the busy hum of the "factory," where woollen and cotton fabrics, paper, &c. are produced at a rapid rate. The observing young student in mechanical philosophy,

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294. May these varieties of motion be modified or varied? Motion of the water wheel. The common spinning wheel.

295. Examples of circular motion changed to rectilinear.

296. Machines in family use, mills, &c.

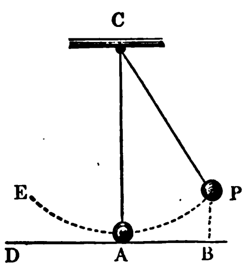
can never, therefore, be at a loss for examples or illustrations of the science. Whether he travel by land or by water, or sojourn in city or country, he will see in every motion, either of animate or inanimate objects around him, something to remind him of the laws and principles which he has already learned, or to suggest new applications of them. Even his own frame, in every motion of its muscles, is a living and moving example of the great laws of mechanical philosophy.

LECTURE XVI.

THE PENDULUM.

297. The oscillation or vibration of the pendulum is the effect of gravitation. This simple instrument, not only *affords the means of ascertaining the variation of the force of attraction* in different latitudes, thus *furnishing a standard of weight*, but its vibrations give the most accurate *method of measuring time.*

Fig. 101.



298. Let P C represent a *pendulum* consisting of a heavy body, P, attached to a wire, which is fastened at the point C, and is movable around it. If the body P were left free, or not retained by the wire, it would fall in the line P B, vertical to the earth's center; but being thus retained, it is forced to describe the arc P A, which is the segment of a circle, of which P C is the radius. The body P acquires a velocity in falling through P A that has a tendency, when it arrives at the point A, to carry it off in the tangent A D; but being prevented from moving in a straight line by centripetal force, viz: that of the wire, which continually draws it towards the center, it is forced to describe the curve A E. In the pendulum, we see an illustration of the effect of gravitation in accelerating and retarding motion; thus from P to A, or downwards, the pendulum moves with accelerated motion, while from A to E, or upwards, the motion is retarded, until the force of projection being overcome by gravitation, it descends with accelerated velocity to-

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297. Cause of oscillation. Use of the pendulum.
298. Explain the motion of the pendulum.

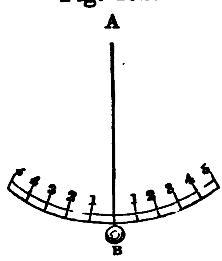
wards A. Were it not for the resistance of the air and the friction of the suspending line on the point of suspension, or some other accidental obstruction, a pendulum once set in motion would, like the planets in their orbits, continue its motion forever.

299. Each swing of the pendulum is called a *vibration*, or *oscillation;* these vibrations are described in *equal times*, whatever be the extent of the arc passed through. Thus this simple instrument, by means of its connection with a few wheels, has become a time-keeper, warning us at every vibration, that the number of our allotted moments upon earth is becoming less and less.

300. The philosopher Galileo was led to the invention of the pendulum, by observing the motion of a chandelier hanging from the wall of a church in Pisa. Seeing that when put in motion, it vibrated with uniformity, as to time, he was led to make experiments that established what is termed the law of *isochronism*,* or equality of time.

301. Though the resistance of the air passed through by the pendulum at each vibration, does, in fact, weaken the vibration, so that every successive arc of a circle described becomes somewhat lessened; yet, as the *rate* at which it moves, becomes *slower* as the space passed through is *shorter*, a large vibration is performed in the same time as a smaller one. Thus the ball B, suspended from the point A, moves from 5 to 5, from 4 to 4, &c. in the same time as from 1 to 1; for, in proportion as the arc described is more extended, the steeper are its beginning and ending, and the more rapidly the pendulum falls, and passes through the intermediate space.

Fig. 102.



302. Every person of common observation must have noticed the wheels, weights, and pendulum, which belong to that curious machine, a clock. The *weight* is attached to a cord which is wound round a cylinder called the barrel, and this barrel revolves on an axis. The suspended weight pressing downwards by the force of gravitation, draws upon the cord, which, gradually unwinding, moves the barrel. This motion is communicated to a small wheel, which, in its turn, communicates motion to a series of

* From the Greek *isos*, equal, and *kronos*, time.

299. Vibrations in equal times.
300. Observations of Galileo. What is meant by Isochronism?
301. Cause of the equal time of vibrations.
302. What belong to a clock? Describe the action of the weights, its office, &c.

large and small wheels. Thus, *the office of the weight is to turn all the wheels, and keep the pendulum* (the axis of which is attached to the machinery,) *in motion.* When the pressure of the weight has drawn all the cord from the barrel, the clock stops. It may be "set going," or put in motion again by "*winding up*;" that is, raising the weight by winding the cord around the barrel wheel, so that its gravitating force may again act upon the machinery.

303. We have already observed that a pendulum, once set in motion, would continue to vibrate were it not for certain opposing forces, viz. friction, and the resistance of the air, and would thus, without the aid of machinery, afford an exact measure of time, and an instance of *perpetual motion.* But some degree of force must be applied, to counteract the impediments to its continued motion; and this force is obtained in the clock, by the *pressure of the weight upon the cord.*

304. The *main spring* of a watch, answers the same purpose for communicating motion to the wheels, as do the *cord and weight* of a clock. The motion of the wheels of the clock is regulated by the *pendulum*, the motion of the wheels of the watch is regulated by the *balance wheel.*

305. The motion of the hands is produced by the operation of ingeniously contrived wheels, fitted with teeth or cogs, so as to give motion to other wheels. One wheel having sixty such teeth, turns round once for sixty beats of the pendulum of the clock. The pendulum being so graduated as to beat *seconds*, one revolution of this wheel is therefore made in sixty seconds, or one minute. An index fixed on the axis of the wheel, and projecting through the dial plate, is called the *second hand* of the clock. Another wheel is so connected with this, and the number of teeth so proportioned, that it turns sixty times slower, in order to carry a *minute hand* upon its axis; and another wheel, by moving twelve times slower than that which carried the minute hand, is fitted to carry upon its axis the *hour hand.*

306. Though "a clock is nothing more than a piece of mechanism for counting the swings of a pendulum," its advantage to mankind is incalculable. Before its invention, men made artificial divisions of time in various imperfect methods, as by observing the regular dropping of water, the running of sand in the hour-glass, the shadow upon the sun-dial, &c.

307. *The length of the pendulum influences the time of its vibra-*

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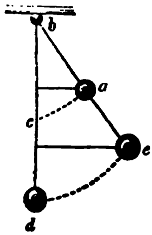
303. Force which keeps the pendulum in motion.
304. Moving power in a watch—how is the motion in a watch regulated?
305. Motion of the hands of a clock, how produced?
306. Different modes of dividing time.
307. Effects of lengthening the pendulum. Rule.

tion. Long pendulums vibrate more *slowly* than short ones, because in corresponding arcs of circles, the ball of the long pendulum has a greater distance to pass over without having a steeper line of descent. If a pendulum, *b a*, be twice as long as another extending from *b* to *e*, it has twice the length to fall in its descending arc *c a*, as the other in its arc *d e*; its movement will, therefore, be proportionally slower, according to the laws of gravitation; that is, *the time of the vibration will increase, as the square root of the length of the pendulum increases.* If a pendulum *one yard* long, would make *one vibration* in *one second*, a pendulum *four yards* long, would vibrate once in *two seconds*, and a pendulum *nine yards* long, would *vibrate once* in *three seconds*, &c.

Fig. 103.



308. The pendulum being usually of metal, is liable to *variations in length, from changes in temperature.* In *summer*, being dilated or lengthened by heat, *it vibrates more slowly* than *in winter*, when, owing to the loss of caloric, *it becomes shortened.* Though the difference in the length of pendulums, and their consequent variation in time, is slight, it is of some importance, and various methods have been invented for obviating this irregularity. The length of a pendulum for vibrating seconds, in our latitude, is about thirty-nine inches.

309. Since the vibration of the pendulum depends on the force of gravity, it follows that pendulums of the same length will vibrate quicker when the force is greater. As the force of gravitation decreases as the distance from the earth's center increases, the vibration of the pendulum is slower upon the summit of a high mountain than at its base. Any change in the force of the earth's attraction would, at once, vary the motion of the pendulum and prevent clocks from measuring time truly. In mines and deep caverns of the earth, though the pendulum is nearer the earth's center, the weight or gravity of the great mass of matter above, counteracts the central force, and attraction is therefore less than at the surface, and the pendulum vibrates more slowly.

310. At the equator, the oscillations of the pendulum are slower than at any other point on the surface of the earth. This is owing to the form of the earth, which is bulging at the equator, and flattened at the poles, so that at the equator, the pendulum is far-

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308. Effect of temperature upon the pendulum. Length of a pendulum for seconds.

309. Why the pendulum vibrates slowly on high mountains and in mines

310. Vibration at the equator.

thest from the center of the earth. The centrifugal force arising from the earth's motion, being also greater at the equator, has the effect to counteract the force of gravity.

311. As the attraction of gravity is in proportion to the mass of matter, the quantity of weight attached to the pendulum, or the weight of its ball, has no effect upon the speed of vibration, except that which results from the resistance of the air. Experiments upon the pendulum, to be perfectly accurate, should, therefore, be made in a vacuum.

312. The pendulum is not only of importance in regulating our divisions of time, and thus enabling us to systematize the business of life, but it affords the only sure mode of determining the variation in the force of gravity in different latitudes, and at different heights. While it serves to amuse the child by its regular and continuous motion, it furnishes problems to the Philosopher, the solution of which requires the most intricate and profound mathematical calculations.

LECTURE XVII.

LOCOMOTION.

313. Before closing the subject of mechanics we will consider the wonderful improvement, which this sciencee, aided by chemical discoveries of the nature and powers of steam, has effected in the rapidity of locomotion.*

314. But, first, let us imagine the state of our own country, when our ancestors planted themselves here. The Indian had no roads; his wandering life led him to traverse mountains and forests for game, and to follow the winding stream for fish. Fine roads and convenient carriages, would, to him, have been superfluous. In the first journey from Plymouth, Mass., to Windsor, Conn., undertaken by our pilgrim fathers, they traveled through a

* From two Latin words, *locus*, place, and *motio*, motion, signifying motion from a place.

311. Weight of the ball does not affect vibration.
312. Why should experiments be made in a vacuum?
313. The science of mechanics connected with locomotion.
314. Former state of our country in regard to roads.

trackless wilderness, bearing the wife of their minister, Mr. Hooker, on a litter. Several weeks were required to perform the journey. There were no bridges across the streams, and the weary travelers must seek for fording places directed by accident alone; searching their way through the defiles of mountains, and meeting often with obstacles which obliged them to retrace their steps and take a new direction. In perils from savage men and ferocious beasts, they encamped at night beneath the canopy of heaven, trusting in the protection of that Being whom they sought to worship in sincerity and truth.

The first roads and bridges constructed in our country, were of a rude and temporary nature. Carriage roads were unknown long after the paths were traced leading from one settlement to another.

315. Science furnishes rules for the construction of roads; and in these days, when new roads are to be made, they are not as formerly left to chance, or the rude skill of the ignorant; but civil engineers are called upon to survey and graduate them, according to the laws of mechanical philosophy.

"The province of the engineer, is to surmount the difficulties presented by *friction*, *gravitation*, *collision* and *road surface*. He must consider the traffic upon the intended line of road, and determine whether a saving of tractive power, will compensate for the outlay of capital required to form the road. The quality of the road must depend on the means of making and supporting it; and there are situations in which it would not be judicious, even to attempt to make any road at all."*

316. From common roads for carriages, we have gradually passed to *canals*, *McAdamized roads*, and *rail-ways*. In canal conveyance, a difficulty has been suggested, founded on the well known law of mechanics, *that the resistance offered by water to a boat in motion, increases as the squares of the velocity.* But Gordon suggests, that if canal boats were differently constructed, their speed might be greatly increased, without increasing the resistance of the water. He would have the horizontal, or propelling force, so great, as to allow little opportunity for the force of gravitation to act upon it, and thus cause the boat to *skim the surface of the waters*, rather than, by suffering it to become deeply immersed, to have the resistance of a large body of the fluid to overcome. Thus, in the case of a number of cannon balls laid in a single

* *Gordon on Locomotion.*

315. Science important in the construction of roads. Circumstances to be considered by the engineer.

316. Supposed difficulty in canal conveyance. How obviated

tier, upon a level surface, and in contact with each other, if one should attempt to move the furthermost ball, by a slow motion in a line with the others, he must communicate motion to them all, and therefore be obliged to use a force much greater than would have been necessary, if, with a quick motion, he had drawn the ball above the others, and moved it over their surfaces.

It is said, that on the Paisley canal, in Scotland, boats are moved by horse power, at the rate of ten miles an hour; and it is suggested that by the use of steam instead of animal power, the velocity may be increased, and the expense of locomotion lessened.*

317. *McAdamized roads* are intended to prevent the resistance of surface. Stones broken into small fragments are laid upon the road to the depth of ten inches. Mr. McAdam considered, that a road thus constructed would be smooth and durable; and that the nature of the soil below the coating of broken stones, was of no importance. This kind of road, though an improvement upon the ordinary turnpike, does not answer all the valuable purposes supposed by its projector. It is found to be, not only very expensive in the outset, but to require almost constant repairs.

318. In the construction of *rail roads*, and the application of steam power to locomotion by land, we see the greatest triumph of modern improvement. Instead of the nerves and sinews of animals, strained to their utmost extent to drag their ponderous loads, is substituted the power of the light elastic steam, an agent which can suffer no pain, and consumes no food. About the year 1770, Oliver Evans, an unlearned American mechanic, happening to make some observations on the elastic power of steam, conceived the idea that it might be turned to some account in moving machinery. He was confirmed in his opinions by experiments. But when he predicted, that "the child was then born who would pass in carriages propelled by steam, at the rate of at least fifteen miles an hour," he was thought to be insane. Rail roads were first made in England; they are now numerous in our own country, and by their means, and the aid of steam boats, a rapid communi-

* Could we see on our great western canals, packets moved swiftly by steam, the scene would be far more pleasant than that exhibited by the slow motion of jaded animals; and a great advantage would be afforded in the increased facilities for locomotion and transportation. But it remains to be proved that Mr. Gordon's plan of avoiding the resistance of a large portion of fluid can be acted upon by means of any construction of boats, or pecu iar mode of applying the motive power. Dr. Lardner, and some other scientific men, do not admit the practicability of any plan of the kind.

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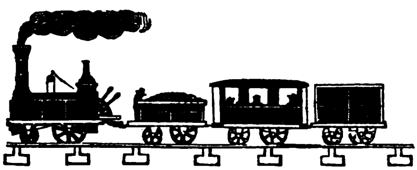
317. McAdamized roads.

318. Rail roads. Rapid traveling. Effects of rapid communication up *the prosperity of the country.* Mode of constructing rail-ways.

tion and intercourse is maintained thoughout its vast extent. The effect of this connection of places, once considered distant, is very important upon the wealth, comfort, and improvement of society. The country merchant, after purchasing his goods in one of the large cities, is not obliged to lie out of his capital, as he was when dependant upon the former slow modes of conveyance. If there be, at any time, a deficiency of any article in one part of the country, there is soon a rapid pressure of it flowing from those places where it is more abundant. A quick and general circulation of the produce of the earth, of articles of commerce, and of literature, is to a nation, what the healthy circulation of the blood is to the human system.

We shall, hereafter, consider the manner in which steam is made to act as a moving power. We are now to notice its application to land carriage. Rail roads, or *rail-ways*, are made by laying horizontal bars of iron for the wheels of the cars to run on.

Fig. 104.



The wheels are confined within the track by a *flange* which constitutes a part of their structure. The figure shows a *locomotive* engine, with the wheels upon an iron rail way. The engine is followed by a *tender*, containing the engineer, with a supply of fuel and water. The train of carriages or *cars* attached, varies in number according to the number of passengers and amount of goods to be conveyed.

319. When horses are the motive power, the less the wheels of the carriage to which the horse is harnessed, or those of the train following, adhere to the rails, the more easy it will be to move the train. But when a locomotive is to be impelled by the action of a steam engine in turning the wheels, if the resistance by gravity and friction be greater than is the force with which the wheels adhere to the rails, the engine will only revolve the wheels to which it is geared; these will turn upon the rails, while the locomotive and whole train attached to it will remain stationary. To prevent this, different contrivances have been resorted to.

320. Another step in locomotion, which seems about to be taken, is that of the construction of steam carriages to run on com-

319. Adhesion of the wheels of the carriage to the rails a disadvantage when horses are the moving power. The case is different when a carriage is moved by a steam engine.

320. Steam carriages for common roads.

mon roads, which shall go up hill and down, without any aid from machinery, other than the proper regulation and adjustment of the motive power. In England, many trials have been made to this effect, and a committee appointed by the House of Commons have reported favorably upon the project. The Committee gave it as their opinion that the advantages of steam power are not confined to the greater velocity thereby obtained, nor to its expense, as compared with that of horse power. But they think, in relation to the use of horses, that danger as well as expense, is increased by increasing velocity. In steam power, on the contrary, there is no danger of being run away with; and the risk of being overturned, is greatly diminished. Steam is found to be perfectly controllable, and capable of exerting its power to retard the motion in going down hills. It can be stopped or turned with the slightest exertion, and under circumstances where horses would be unmanageable. Sounds or sights can have no power to affright this unconscious agent which labors so effectually for mankind.

If we could believe all that is predicted with respect to improvements in the application of steam, we may expect to see the day when the farmer's plow and market wagon, the pedler's cart, stage coaches, and private carriages will be moved by steam power; and when steam for the purposes of locomotion, will be as common in every family, as are now a coffee mill, a patent churn, or a washing machine.

PART III.

HYDROSTATICS.

LECTURE XVIII.

MECHANICAL PROPERTIES OF LIQUIDS.

321. There are, in nature, three distinct forms under which substances exist; viz; *solids*, *liquids*, and *gases*. *Wood*, *water*, and *air*, are examples of each class. Many of the mechanical laws which govern solid bodies, equally apply to liquids and gases; but, as the latter have properties peculiar to themselves, it follows that each class is subject to its own peculiar laws.

322. Under the general name of *fluids* are included *liquids* and *gases*; the former are called *non-elastic* fluids, the latter, *elastic* fluids.

323. The name of *non-elastic fluids* was given to liquids from the supposed fact that they were in no degree elastic, or compressible. Common air, steam, and other elastic fluids, are easily compressed, and on removing the pressure they expand to their original dimensions. This may be proved by pressing an inflated bladder. A bag of leather or India rubber, filled with water, and secured so that none of the liquid can escape, may be burst by forcible compression, but cannot be made to exhibit any sensible degree of contraction. Water, from its powerful resistance to pressure on all sides, was long considered as perfectly incompressible. An experiment made by some Philosophers at Florence, in the sixteenth century, confirmed this opinion. A hollow globe of gold filled with water and closed tight, was subjected to the powerful action of a screw-press. The water did not become com-

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321. Substances exist under three forms. Liquids and gases subject to peculiar laws.

322. How are fluids divided?

323. Are liquids compressible? Experiments of Philosophers at Florence. Experiments of Perkins.

pressed so as to occupy less space, but forced its way through the pores of the dense metal, and appeared like dew on the outer surface of the globe. Though this experiment was long considered conclusive proof that *water* cannot be compressed, later trials have shown that though its resistance to pressure is very great, it will yield, in some degree, under a certain weight. Experiments by Mr. Perkins, before the Royal Society of London, proved that a weight of 2000 atmospheres, (or a weight 2000 times as great as that of the atmospheric column,) diminished the bulk of water *one twelfth part.*

But so inconsiderable is the degree to which liquids can, by any ordinary force, be compressed, that in all calculations respecting their action, they are regarded as *incompressible fluids.*

324. Solid bodies are subject to the power of cohesive attraction in a much greater degree than liquids ; and the latter, in a greater degree than gases. The parts of a solid are connected together, so as to form one whole ; their force of gravity is therefore centered in one point, which, if supported, prevents the whole from falling. In fluids, (although each atom has its own center of gravity,) the parts have not a common center of gravity, therefore, as soon as a vessel is filled with any liquid, each additional drop runs off at the sides.

325. *The same substance may exist in the form of a solid, liquid, gas, or vapor.* Ice is solid ; expose it to the influence of heat, and it assumes the liquid state ; an additional quantity of heat causes this liquid to become steam or vapor. Mercury is commonly seen in the form of a very dense liquid, quick-silver ; but it may, like water, be condensed or frozen by exposure to a very low temperature, and made to boil or evaporate, by subjecting it to a great degree of heat.

326. HYDROSTATICS, (from two Greek words, *udor*, water, and *statos*, standing,) is the science which treats of the *weight*, *pressure*, and *equilibrium* of liquids.

327. Liquids afford an example of a state in which cohesive attraction is exactly balanced by the repulsive principle, heat. Water, by losing a certain portion of heat, is given up to the power of attraction, and, its particles cohering, it becomes a solid. By the addition of heat, the particles of water are driven to a greater distance, and the liquid changes to a light and expansive vapor. Oil, deprived of heat, congeals into a solid ; by the addition of heat, it becomes the gas, known in chemistry, as *olefiant* or oil-gas.

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324. Liquids have less cohesion than solids. Proof.
325. The same substance may exist in different forms.
326. Of what does Hydrostatics treat?
327. Attraction and repulsion balanced in liquids.

328. The particles in liquids being freely movable among each other, yield to the least disturbing force. These particles are supposed to be round and smooth, because they move easily and without friction. This supposition accounts for some properties of liquids which could not, otherwise, be well explained. For instance, water will take up a certain quantity of sugar without being increased in bulk; again, a certain portion of salt may be added and yet the original bulk of the water remain the same.

Fig. 105.

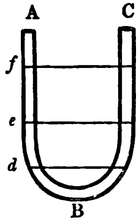
Let us suppose a vessel to be filled with cannon balls; it is evident that it can hold no more balls; but a quantity of small shot might find their way into the spaces existing between the large balls; and when no more shot could be added, sand or ashes might be introduced to fill up the spaces between the shot; and water might afterwards be added to fill up the spaces between the particles of sand. It is a well known fact that a cask filled with ashes, will receive a large quantity of water, added gradually, so as to give time for the water to penetrate the interstices between the particles of ashes. Now admitting the spherical form of the particles which compose liquids, we can perceive the reason that some liquids will receive into the spaces between them, smaller particles of other substances.

Pressure of Liquids.

329. Liquids press not only *downwards* like solids, but *upwards* and *laterally*, and *the pressure is equal in all directions.*

330. We will first show the *upward pressure of liquids.* Let A B C, represent a bent tube of glass. Now if by means of a funnel, you pour sand into a tube at A, the sand after filling the lowest part of the tube, will rise, until the side A B is full; after which, if sand be poured into the funnel, it will run over the top of the tube at A. If instead of sand, you pour water, or any other liquid, into the tube, at the mouth A, you will find the fluid to preserve a *level* on both sides of the tube; a small quantity would fill the bottom, and would rest at the line *d;* an additional quantity would carry the height of the fluid to the line *e*, and another portion would raise it to *f*. This experiment proves the *upward pressure* of liquids, since the water, by this force, is raised in the side C B, contrary to the laws of gravitation.

Fig. 106.



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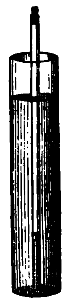
328. Particles in liquids. Liquids will take up portions of certain substances without any increase of bulk.
329. Pressure of liquids.
330. Upward pressure illustrated. Exp. 1.

Fig. 107.



331. Exp. 2d. Let the glass jar or cylinder, A B, be nearly filled with water, while a glass tube, *a b*, (open at the top,) is pressed so closely upon the bottom of the jar as to prevent the entrance of any of the liquid; the tube being raised a little, the *upward pressure* of the water will cause it to rush up into the tube until it is on a level with that in the jar. On taking the tube out of the jar, the water runs out, and air rushes in to supply the vacuum. Stop the tube at *a* with a cork, and plunge it again into the water; the liquid now, rises no higher than *b*. This is because the tube was filled with air, and matter being impenetrable, no two substances can, at the same time, occupy the same space. If the tube were not closed at the top, the water, being the heavier substance, would press the air upward and take its place, as proved by the experiment. It may be asked, "if the tube be filled with air, and if this cannot escape, how can the water enter the tube?" We answer that air being *compressible*, the upward pressure of the water has forced that which before filled the tube, into a smaller space; for, it is evident, that as none has escaped, it must be contained in the space between the cork and the top of the water, *b*. *The same quantity of matter being compressed within less space*, it follows, that the air in the tube is more *dense* than before compression.

332. Though air is thus easily compressed, great force is required for the compression of water: let a glass tube be corked at the top and filled with a colored liquid; hold a piece of pasteboard close to the other extremity of the tube, to prevent the escape of the liquid, and plunge the tube into a tumbler of water; if you remove the pasteboard, and plunge the tube to any depth of water, the colored liquid will still keep its place, and will not, like air under similar circumstances, show that the upward pressure of the water has any power to cause it to occupy less space.

LECTURE XIX.

PRESSURE OF LIQUIDS.

333. The *lateral* or *side pressure* of liquids, is equal to the pressure either upward or downward. That the lateral pres-

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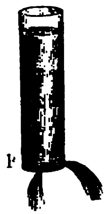
331. Exp. 2. What causes the water to rise in the tube? Exp. 3. Why does not the water rise as high as in experiment 2.

332. Water not easily compressed.

333. How is the lateral pressure of liquids proved?

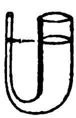
Fig. 108.



sure is equal to the pressure downward, may be illustrated by the following experiment. Let the vessel, A B, be filled with water, and let two orifices of equal dimensions, *a* and *b*, be made, the one at the bottom, the other at the side of the vessel. Let the water run into two receivers, and it will be found at the end of a given time, that the quantity of liquid which has escaped, is equal in both receivers. This proves that the lateral pressure is equal to the pressure downward. The opening at the side is made quite at the lower part of the vessel; were it higher, the liquid would not flow out with equal velocity, as, the greater the weight of the column above, the greater the force of the downward pressure; *therefore, in this experiment, the perpendicular height of the two orifices must be equal.*

334. From the force of pressure in different directions, water poured into a bent tube, called a *syphon*, will stand equally high in both sides. If the communicating tubes are of *different diameters*, still the fluid stands at the same height in both; therefore *a portion of liquid, however small, will resist the pressure of a portion however large,* and will balance it.

Fig. 109.



335. In a common tea pot, we see an illustration of this law, as water poured into the body of the vessel, will rise to the same height in the spout as in the body of the vessel; and if poured into the spout, the small column in the latter would still be forced to balance the whole column, in the main portion of the vessel.

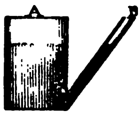
Fig. 110.

336. So strange did this law of nature appear, when first discovered, that Philosophers termed it the "*hydrostatic paradox.*" This phenomenon may be explained on mechanical principles. *Opposite forces have been shown to be equal when their momenta are equal*; that is, *what is wanting in weight may be made up in velocity.* In mechanics, it is an established law, *that the power and weight balance each other, when the power moves as much faster than the weight, as the quantity of matter is less.* Let this law be applied to the case which we are now considering.

Suppose the aperture A, (Fig. 111,) to be ten times the size of B; then a quantity of water one inch in height in the spout B, would rise

334. Liquid in a bent tube. In a tube varying in diameter.
335. What law illustrated by Fig. 110?
336. What is the hydrostatic paradox? How may it be explained on mechanical principles?

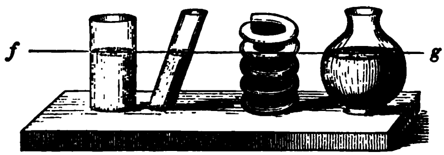
Fig. 111.



in the vessel, A, but one tenth part of an inch; or a certain quantity of liquid would rise through a space of ten inches in the tube B, while it would rise but one inch in the vessel A. Thus we find that there is in reality, nothing more wonderful in the hydrostatic paradox, than that one pound at the long end of a lever should balance ten pounds at the short end.

337. *The velocity of columns of water, when in motion, being as much greater in the smaller columns, as in the larger columns the quantity of matter is less*, it follows that in vessels of various sizes and shapes, connected with a common reservoir, the liquid will rise to the same level, *f g*, in all; here the *water being considered the weight, and pressure the power*, the weight and power may be said to be in equilibrium, where the fluid is on a level in each of the vessels. Thus we find that, in all situations, fluids at rest maintain a level or horizontal position.

Fig. 112.



338. *The whole mass of liquid, and the sides of the containing vessel are affected by the slightest compression.*

Fig. 113.

In a quantity of liquid subjected to compression, the whole mass is equally affected; and, hence, if a cork be forcibly driven into a bottle full of water, the pressure will be felt alike in every portion of the liquid, which will press against the sides of the bottle in all directions, causing it to break at that point which is weakest, however situated in relation to the mouth or where the force was applied.

339. *The pressure of a column of liquid is in proportion to its perpendicular height.*

By this proposition we mean, that the pressure of any liquid

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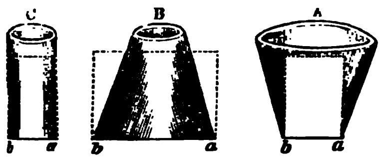
337. Why do liquids rise, in various shaped vessels, to an equal height, when connected with a common reservoir?

338. Does compression on any portion of a fluid affect other portions in the same vessel? Experiment.

339. Proposition. What is meant by "*pressure according to height?*" Suppose the containing vessel *wider* or *narrower* towards the top, or of an equal diameter throughout. Experiment to prove that one pint of water *may be* made to balance twenty pints.

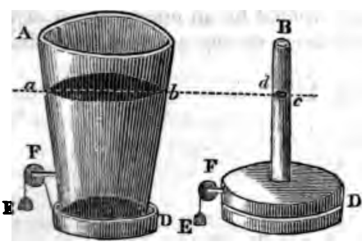
upon the bottom of a vessel, is *not according to the quantity contained but according to the weight of a perpendicular column, having for its base the bottom of the vessel, and for its height the depth of the liquid.* If the vessel become wider towards the top, as in A, the pressure at the base is less than the weight of the whole liquid, it being denoted by the shaded perpendicular column, the base of which is *b a*. If the vessel become narrower from the base, as at B, the pressure at the base is greater than the weight of the liquid, as denoted by the dotted lines. When the vessel is, throughout, of an equal diameter, as in C, the pressure on the bottom is equal to the weight of the whole liquid.

Fig. 114.



Suppose two vessels to have their bases equal, but the vessel A holds twenty times more than the vessel B; that is, A holds twenty pints, while B, holds but one pint. Each vessel has a brass bottom, D, opening like the lid of a box. A pulley, F, supports a weight, E. Let the vessel A be supported by its sides, and water poured in until the pressure of the liquid begins to raise the weight, and of course to open the lid-like bottom, when the water will begin to escape. Let the height, *a b*, be marked, at which the surface of the water stands when the bottom begins to give way. Try the other vessel, B, in the same manner, and it will be seen that when the water is at the height, *c d*, the weight will begin to rise, and the bottom to fall. Let *c d* be continued to *b*, and it will be seen that the two lines *a b* and *c d* are on the same horizontal plane; therefore the height of the two columns are equal. Here we see, that equal weights are overcome, in the one case by twenty pints of water, and in the other case by one pint, and therefore that one pint of water may be made to balance twenty pints.

Fig. 115.



340. The law we have now explained and illustrated, viz; that

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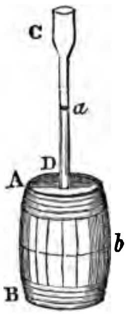
340. Why will a cask when filled with liquid, burst with the weight of a very small column of liquid.

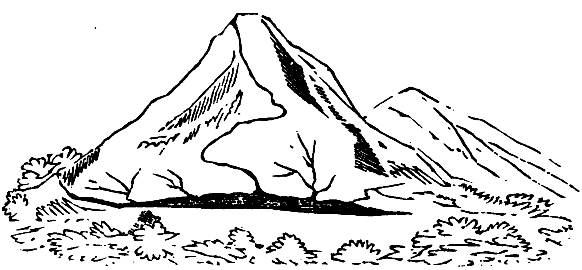
Fig. 116.



the *pressure of a column of liquid is in proportion to its perpendicular height and base*, explains why a cask when filled, may be burst by the additional weight of a few ounces of liquid. Suppose the cask A B to have C D, a tube several feet in length, inserted at its top; on filling the tube with water, the compressive force will be in proportion to a column, the height of which is the height of the tube, and the base, the top of the cask; therefore, the pressure upon the cask is the same as if a column, equal in diameter to the whole diameter of the cask, extended to the top of the tube.

341. Many of the convulsions of nature, manifested by broken and scattered rocks, have been caused by *hydrostatic pressure.* Since a column of water, only a few feet in height, is capable of bursting a hogshead, by the force of its pressure, what force might not be exerted by a column of water contained in the fissure of a mountain, extending several hundred feet in depth. "Suppose in the bowels of a mountain there should be an empty space of ten yards square, and only an inch deep, on an average, in which a

Fig. 117.



thin layer of water had lodged, so as to fill it entirely; and suppose that in the course of time, a small crack of no more than an inch in diameter should be worn from above, 200 feet down to the layer of water; if the rain were to fill this crack, the mountain would be shaken, perhaps rent in pieces, with the greatest violence, being blown up with a force equal to the pressure of above

341. Effect of water pressure in rending mountains.

5022 tons of water, though only 2½ tons had been actually applied."*

342. The *hydrostatic or water-bellows*, is an article of philosophical apparatus which illustrates the pressure of fluids. A long tube communicates with the body of the bellows; this consists of two oval boards, connected by folds of leather like the common bellows. When the tube is filled with water, the pressure upon the upper part of the bellows will be such, as not only to raise the board, but to sustain heavy weights placed upon it. The force of the pressure, (when the tube is full,) will be equal to the weight of a column of water, whose base is as the surface of the bellows, and whose height is as the length of the tube. It will readily be perceived that the pressure of a certain quantity of water may be increased by making the circumference of the bellows larger, and the tube smaller and longer; as, by so doing, the base and height of the column will be enlarged. If the tube hold an ounce of water, and have an area equal only to one thousandth part of that of the upper board of the bellows, one ounce of water in the tube, will raise, or balance a weight of a thousand ounces resting on the bellows.

Fig. 118.

343. If mercury were substituted for water, in a similar machine, the effect of the fluid pressure would be fourteen times greater, because the same bulk of mercury is fourteen times heavier than water. Air, which is an elastic fluid, may also produce powerful effects in the same manner;—if a bellows were sufficiently large in diameter for a man to stand upon, he might, by blowing into a perpendicular tube with his mouth, raise his own weight by the pressure of the air acting upon the bellows.

344. The principle of hydrostatic pressure has been applied to the construction of a very powerful press, called the *hydrostatic or water-press*. So great is the force thus obtained, that with a machine no larger than a common tea-pot, a bar of iron may be cut as easily as a strip of pasteboard with a pair of shears. Instead of the tube of the bellows, the water-press has a small pump; and

* See Treatise on Hydrostatics, Library of Useful Knowledge.

342. Explain the principle on which the hydrostatic bellows is constructed. Force of the pressure of the column of liquid in the tube. Suppose the circumference of the bellows were larger, and the tube of less diameter but of greater length.

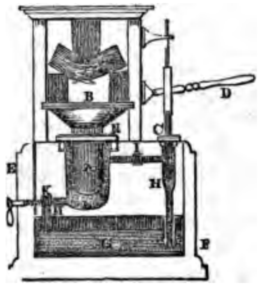
343. What would be the effect of substituting mercury for water in a similar machine? Might not air be used instead of water or mercury?

344. Application of the principle of hydrostatic pressure. Power of the water-press.

for the body of the bellows is substituted a pump barrel and piston.

345. In the seventeenth century, Pascal, a man no less celebrated for learning than for piety, discovered the principle of hydrostatic pressure; he asserted that an engine might be constructed, acting through the force of a column of water, by means of which, one man, pressing on a small piston, might resist the efforts of a hundred men brought to bear on the surface of a large piston. This imaginary machine was termed by its projector, "*a new machine for multiplying forces to any required extent.*" It was not, however, until more than a century afterwards, that any practical application was made of this force.

Fig. 119.



"Bramah's *hydrostatic press*" (Fig. 119,) consists of solid masonry, or strong wood work, E F, firmly fixed, and connected by uprights with a cross-beam. B represents a strong table, moving vertically in grooves between the uprights; and any substance to be pressed or broken, is placed in the space above it. B is supported beneath by the piston A, which works within the hollow cylinder L, and passes through a collar N, fitting so closely as to be water-tight. From the cylinder passes a small tube with the valve opening inwards at I. D is a lever which works the piston of a small forcing pump, C H, by which water is drawn from the reservoir G, and driven into the cylinder L, so as to force up its piston A. At K is a valve, which being relieved from pressure, by turning the screw which confines it, a passage is opened for the water to flow from the cylinder, through the tube M, into the reservoir G, allowing the piston to descend.

The effeetive force of such a machine must be immensely great, combining as it does, the advantages of solid and liquid pressure. The amount of the latter is to be estimated by the relative diameters of the two pistons; so that if the piston H be half an inch in diameter, and the solid cylinder or piston A one foot, the pressure of the water on the base of the piston A, will be to the pressure of the piston H on the water below it, as the square of 1 foot or 12 inches, $12\times12=144$, to the square of $\frac{1}{2}$ an inch, $5\times5=25$; that is, as 144 square inches to $\frac{1}{4}$ of a square inch, or in the ratio of 576 to 1.* To this must be added the advantage afforded by the lever-handle of the forcing-pump, depending on the relative lengths of its arms; and supposing the power to be thus increased *tenfold*, the effect of the machine will be augmented in proportion, or will become as 5760 to 1.†

* The pupil will need some knowledge of *decimals*, to understand this statement; 5 is the decimal of half an inch,—the square of 5 is 25 or $\frac{1}{4}$ of a square inch. Multiplying 144 by 4, we obtain the number 576, and thus the advantage here obtained by liquid pressure, is as 576 quarters of inches to 1 quarter of an inch.

† Moffat's Book of Science. London.

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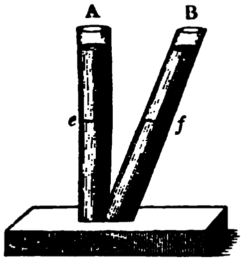
345. Describe the water press of Bramah. Mode of estimating the advantage of a water-press of known dimensions.

346. The hydrostatic press is applied to various important purposes; to compress hay, cotton, and other bulky commodities, which may thus be made to occupy on ship-board, a space twenty or thirty times less than in their natural state. It is also used to raise great weights, to uproot trees, and to cut hard substances.

Fig. 120.



347. *The pressure upon any particle of a liquid, is in proportion to its depth below the surface.* Thus, the inclined column B C, being of the same perpendicular height as the straight column A C, both exert the same pressure upon the base C. Suppose *e* and *f* to be half the distance from the surfaces A and B, the pressure upon them is but half as great as upon a particle at C.

348. The cause of this increase of pressure is evident. The fluid atoms being subject to the laws of gravity, the upper layer presses upon the next, which, with double its own weight, presses upon the third layer, and thus the pressure is constantly increasing with increasing depth. For this reason, pipes for aqueducts should be made stronger in proportion to their depth, as also the sides of canals, embankments, &c. The lateral pressure being equal to the downward, it follows that the sides of a canal, or embankment, receive the greatest pressure nearest the bottom.

349. The weight of a solid or cubic foot of water, is 1000 ounces, or 62½ pounds. Now at the depth of 8 feet, as the pressure on a square foot is equal to a column of water whose base is 1 foot, and whose depth is 8 feet, the solid contents of such a column are 8 cubic feet. Therefore, as one solid foot of water is 62½ pounds, and this number multiplied by 8 is 500, it follows that a column of water 8 feet deep, causes a pressure equal to 500 pounds; at 16 feet the pressure is double, or equal to 1000 pounds, and so on in the same proportion. Thus at the depth of 64 feet, or eight times 8 feet, there is a pressure of 4000 pounds, which is ascertained by multiplying 500 by 8. From these facts, we may form some idea of the vast pressure of the water of the ocean, which is supposed to be, in some places, four or five miles deep. The pres-

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346. Uses of the water-press.

347. Pressure proportioned to depth.

348. Cause of increase of pressure. How should this principle affect the construction of aqueduct pipes, canals, &c.

349. Weight of a solid foot of water. Pressure of a column of water 8 feet deep. Of a column 64 feet deep. Pressure of the Ocean. Why deep seas *cannot be sounded. Experiments* on the pressure of water.

sure at the depth of one mile, is equal to the weight of 330,000 pounds. This explains the fact so well known, that in deep seas, it is impossible for the mariner to learn the exact depth by *sounding*, because the lead, which is attached to the cord he uses, floats at a certain depth.

A common square glass bottle (containing only air) if corked and sunk in water to the depth of sixty feet, will be crushed inwards by the pressure. If the bottle be first filled with water, then corked and let down to any depth into the sea, the bottle will not be broken, because the pressure of the liquid within resists the external pressure. At a certain depth, the cork, owing to the compressibility of water, will be forced into the bottle; and this, in whatever direction the mouth of the bottle may point, whether downward, upward, or laterally; for pressure, as has been already explained, is equal in all directions.

350. The downward pressure of the particles of a fluid is occasioned by gravitation; the lateral pressure results from the downward pressure pushing out at the side, with equal force, the contiguous particles. For it must be remembered, that the fluid particles are not supposed to be piled exactly above each other, (as at A,) but to be arranged as cannon balls are usually piled one above another, (as at B.) If the particles below had not a tendency upward equal to the weight or downward pressure of the particles above, they could not support them. Their upward tendency may be considered as derived from the pressure around them.

Fig. 121.

351. Even water itself, which was long supposed incapable of being compressed into a smaller space, is found unable to resist the powerful pressure of its own element. An apparatus has been invented, consisting of a hollow brass cylinder, which being filled with water and closely stopped, is sunk to a certain depth, at which the stopper will be driven inwards. Means are contrived for ascertaining how far the stopper is driven in at different depths. The brass cylinder being full when it was closed, the stopper could not have been pressed inwards, unless some portion of the water within was expelled, or the whole compressed in bulk; and since the cylinder allowed no portion to escape, it follows that the liquid was compressed, and this compression is found to become greater at greater depths. The same experiments have been repeated with the hydrostatic press. It has been proved, that under a weight of 1500 pounds to the square inch, water loses one 24th part of its bulk, and its specific gravity is increased in the same proportion.

Level surface of Liquids.

352. That liquids, when left free to arrange themselves according to their own laws, always maintain a *horizontal position*, is too

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350. Cause of downward and lateral pressure. Of upward pressure.

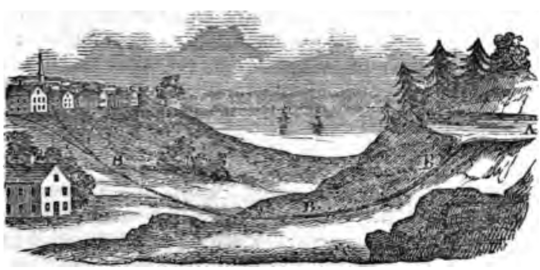
351. Experiment for proving the pressure and compressibility of water. Experiment with the hydrostatic press.

352. Curved surface of the Ocean. Why not perceptible. Tendency of water to seek its level.

familiar a fact to need any illustration. Yet though we speak of the *level of the sea*, it must be recollected that from the spherical form of the earth, the surface of the ocean must be curved. And however small any extent of surface may be, it is not, strictly speaking, exactly level. But from the size of the whole globe of the earth, the general curvature of those portions within the scope of our vision, is too small to affect our sense of sight, or to alter the mechanical laws of nature. From this tendency of liquids to settle into a level, arises the glossy smoothness of the calm lake and still fountain, which reflect the surrounding images as faithfully as the most perfect mirror. If these waters be disturbed, as soon as the exciting cause ceases, they again resume their smooth and equal surface. Water from highlands is continually seeking to make its way downward, in order to find a *level*. Lakes and ponds, in elevated countries, are constantly pressing against their boundaries, and when these give way in the slightest degree, fearful inundations of the country below are the consequence. The beautiful valleys and picturesque glens, which we now behold, were, probably, once filled with water, which, in seeking its level, found some outlet of escape into a lower region.

353. It is upon this *level-seeking* principle in water, that *aqueducts* are constructed, as whether conveyed in artificial pipes, or natural channels, water will rise as high as its source. Suppose a reservoir, A, to be on an elevation at a little distance from a city or village, the water may be brought in pipes or aqueducts, B,

Fig. 122.



through a valley, and then up an acclivity, until it reaches a height equal to that of the reservoir; thus it may be distributed by communicating pipes to every street. The ancients, who were at great expense in the construction of aqueducts, often carried water over

353. Principle on which aqueducts are constructed. Aqueduct bridges of the ancients.

valleys by means of *aqueduct bridges*, instead of conducting it through pipes. For this reason some have supposed that they were ignorant of that law by which liquids rise in pipes or channels as high as their source. But as they did, in some cases, use pipes laid in the earth, for conducting water, it is probable they adopted the more expensive mode of arcades, on account of their greater permanency. For, as the pressure in pipes is greater in proportion to the depth of the water below the reservoir, it follows, that in descending great declivities, the force of this pressure upon the pipes is so great, as ultimately to burst the strongest material.

LECTURE XX.

SPECIFIC GRAVITY.

354. All bodies of equal bulk have not the same weight. A piece of cork weighs less than a piece of hard wood of the same size, and a piece of lead of the same dimensions, weighs more than either. Thus each different kind of matter has its *specific*, or peculiar weight, which is expressed by the term *specific gravity.*

355. The *absolute gravity* of any substance, is its real weight, or the force with which it presses downwards ; the *relative gravity*, or, which is the same thing, specific gravity, is the weight of a substance, compared with others of equal bulk. It is owing to different *degrees of density*, that substances thus differ in regard to gravity. The more dense a body is, the more particles of matter are contained within a certain bulk, and the greater is its specific gravity. For example, lead is a very dense, and cork, a porous body.

356. *Water is the standard for estimating the relative, or specific gravity of solids and liquids.* That is, if a certain bulk of any substance be found to have exactly the same weight as the same bulk of water, its specific gravity is called 1 ; if it be twice as heavy as the same bulk of water, its specific gravity is called 2, and so on. The specific gravity of gold is about 19 ; that is, gold is about 19 times heavier than water.

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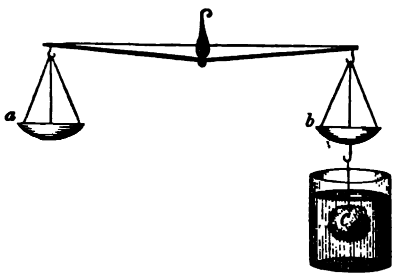
354. Weight not depending on bulk. Meaning of the term *specific gravity.*
355. Absolute and relative gravity. Cause of difference in gravity.
356. Standard for estimating specific gravity. What is meant when the specific gravity of any substance is stated as 1, 2, &c.?

357. *Rule for ascertaining specific gravity.* Weigh the body first in air, (that is, in the common mode,) then weigh it in water; find how much weight it *loses* by being weighed in water; now divide the former weight by the *loss sustained*, and the result will be the specific gravity of the substance weighed, or its relative weight when compared with the weight of water.

Fig. 123.



The figure represents an *hydrostatic balance*. Now suppose *c* to be a solid inch of gold suspended from the bottom of the scale *b*; 1st, let its weight be ascertained, by putting weights in the opposite scale, *a*, and suppose it to be 19 ounces; 2d, place beneath the scale *b*, a glass vessel partly filled with water, the gold is buoyed up by the liquid with a force proportioned to the weight of the water which it displaces, and is found to lose one ounce in weight, or to weigh in water but 18 ounces; 3d, according to the rule already given, divide 19, the weight of the gold out of the water, by 1, the loss of weight sustained in the water, and the quotient 19, is its specific gravity. That is, a piece of gold, weighing 19 ounces, occupies the same space as a portion of water weighing one ounce, or, in other words, gold is 19 times heavier than water.

358. It is found that this *difference* between the weight of the gold in air and in water, gives the weight of a quantity of water equal to the bulk of the metal. This rule is founded on a law in Hydrostatics, that a solid body immersed in any liquid, not only weighs less than it does in air, but that the difference corresponds exactly to the weight of the liquid which it displaces; and, it is evident, that the liquid thus displaced, is of the same bulk as the solid; since the latter fills a space which before, was exactly filled by the liquid.

359. The heavier a body is, the less water will a given weight of this body displace. If we take of gold, silver, tin, and marble, a

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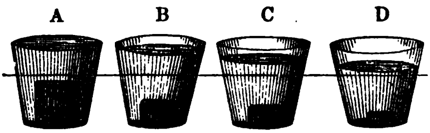
357. How may the specific gravity of a substance be ascertained? Hydrostatic balance. What is the first step in the process of finding the specific gravity of a substance? What the 2d step? What is the 3d step?

358. What quantity of water will weigh as much as the gold loses of its weight in water? How does it appear that the liquid displaced is of the same bulk as the solid which has taken its place?

359. By what experiments can it be proved that the heavier a body is, the less water will a *given weight* displace?

piece of each, weighing one ounce; the ounce of gold will be the smallest of all the pieces, and the marble the largest; for the specific gravity of gold is 19, while that of marble is but 2; tin, though lighter than gold, is heavier than marble; and silver is heavier than tin; therefore the ounce of silver would be greater in bulk than the gold, and less than the tin: the ounce of tin would be larger than that of silver, and smaller than that of marble.

Fig. 124.



Take four tumblers of equal size, A B C D, and containing equal quantities of water, being filled up to the horizontal line; put the ounce of gold into D, that of silver into C, that of tin into B, and the marble into A, the water will be raised or *displaced* in proportion to the *bulk*, and not to the *weight* of the substances immersed.

360. Whatever may be the *form* of different substances, their exact *bulk*, or size, is ascertained by weighing them in water, as from the ease with which the liquid particles move, water accommodates itself to cavities and protuberances. Lumps of minerals of the most irregular forms, may be weighed in water, and their specific gravities ascertained; that is, their *weight* and *bulk compared.* By this means, the mineralogist accurately distinguishes the various genera of minerals. If all substances could be easily formed into regular, solid figures, their comparative gravity could be determined, by simply weighing them in the usual manner; thus, if we suppose a cubic inch of gold, weighing 19 ounces, a cubic inch of silver $10\frac{1}{2}$ ounces, and one of tin about 8 ounces, we could estimate their relative weight accordingly; but most natural substances, such as diamonds and other precious stones, and common mineralogical specimens, are of various, and irregular figures. It is, therefore, very important that there should be a method of estimating their exact bulk, and *comparative weight.*

361. *Specific gravity of solids lighter than water.*

The cases we have considered, are of such substances as are *heavier* than water, and therefore sink in it. When a body is lighter than water, its specific gravity is ascertained by attaching to it some heavier substance which will cause it to sink, and the

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360. Bulk of irregular masses ascertained by weighing them in water. Advantage of this to the mineralogist. If substances were of regular forms, how could their specific gravity be ascertained? Most natural substances irregular in their forms.

361. Mode of ascertaining the specific gravity of substances lighter than water. Experiment to prove the specific gravity of wood.

absolute weight and *specific gravity* of this additional substance being known, it is easy to find, by subtracting from the loss of weight of the mixed mass in water, the loss of the heavy body alone; the difference is the loss of the lighter body.

Suppose we wish to find the specific gravity of *wood*, which, being lighter than water, floats on its surface. The specific gravity of copper is known to be 9; suppose a lump of this metal, weighing one pound to be attached to a piece of wood. According to the method given for ascertaining specific gravity, we have only to subtract from the weight of the whole mass in water, 9 for the whole loss of the copper, and the remainder of the loss of weight in water is that of the wood, or lighter body; which loss being divided by the weight of the wood out of the water, the specific gravity of the wood is ascertained.

Specific Gravity of Liquids.

Fig. 125.

362. The specific gravity of liquids is ascertained by means of a simple instrument, called an *hydrometer.** This is a hollow, floating bulb, B, of glass or metal, with a graduated tube, *a d*; the specific gravity of a liquid may be estimated by the depth to which the hydrometer, when plunged into it, sinks, or by the weight required to sink the hydrometer to a certain depth. Weights are suspended at *c*, for the purpose of sinking the instrument, and keeping it in a vertical position. The weight necessary to sink the instrument to a certain mark on the tube, determines the specific gravity of the liquid into which it is plunged. As the resistance of fluids is in proportion to their density, it follows, that the hydrometer will sink deepest in those fluids which are lightest. This instrument is used by brewers and distillers, to determine the strength of their liquors. It is also used in salt manufactories, to test the strength of the brine. The deeper the hydrometer sinks in spirits, the stronger they are, because alcohol is specifically lighter than water; and the less the spirits are reduced with water, the lighter they are, and, of course, the less resistance they offer to the pressure of the instrument. In brine, on the contrary, the instrument is borne up, salt water being heavier than fresh water, in proportion to the degree of salt which it holds in solution.

* From the Greek words, *udor*, water, and *metron*, measure.

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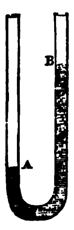
362. Hydrometer. Use of the hydrometer.

363. It is related, by Dr. Arnott, that a merchant in China, who had sold a quantity of distilled spirits to the purser of a ship, according to a sample shown, went into his shop and added to each cask a quantity of water.—The spirit being delivered on board the ship was tested by the hydrometer, and found to be reduced. The Chinese ignorant of any human means by which the fraud could be detected, confidently denied it; but on the exact quantity of water which had been added, being specified, he was seized with a superstitious awe, and, confessing his roguery offered to make ample restitution. When shown the instrument by means of which he had been detected, he was struck with admiration. and offered to purchase it at any price that might be demanded.

364. There are many common facts, the philosophy of which can be understood only by a knowledge of the different specific gravities of bodies. When a person lies in a bath, he feels himself borne up by the liquid around him; but on going out, his limbs seem heavier than usual. The specific gravity of water being greater than air, causes the difference in the sensations, on being surrounded by one, or the other element. Water is said to have no weight in water; thus a bucket in a well is made to ascend with a slight force until it reaches the surface of the water, after which its weight is sensibly felt. Many fishes are nearly of the same specific gravity as water, therefore, when lying inactive, they neither sink nor swim. It is said, that a certain king of ancient times demanded of the learned men of his court, an explanation of the fact that fishes had no weight in water; many profound theories were offered, but none seemed satisfactory. At length an unlearned man, consulting only the philosophy of common sense, balanced a vessel of water in scales, and putting a fish into it, showed that the weight in the vessel was increased by the whole weight of the fish.—For supposing the fish to be of the same specific gravity as the water, that is as 1 to 1, it was the same thing, as if a certain portion of water had been added, which in its own element would lose no weight.

365. *Two columns of liquids of different specific gravities, balance one another, when their heights are, inversely, as their specific gravities.*

Fig. 126.



In the bent tube A B, when the height of the column B is as much higher than that of A, as the liquid B is lighter than the liquid A, the two columns will balance each other and remain at rest, at A and B. As the bases and heights of the columns of fluid, determine their force; this force must of course vary, with the specific gravities of the liquids. Thus mercury having a specific gravity about 14 times greater than that of water, a column of mercury would balance a column of water 14 times higher than itself.

366. "*A body lighter than its bulk of water, will float*, and with a force proportioned to the difference of specific gravity. If the

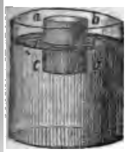
363. Detection of fraud by means of the hydrometer.

364. Why a person feels himself lighter in a bath. A bucket easily raised in water. Question of a certain king.

365. When will two columns of liquids of different specific gravities balance one another? Example. Column of mercury balancing a column of water.

366. Cause of bodies floating in water. Specific gravity of the human body. Cause of its sinking in water.

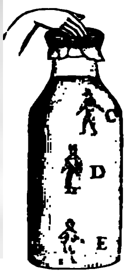
Fig. 127.



cylinder *a b c d*, be partly immersed in water, the upward pressure of the water on the bottom *c d*, is exactly what served to support the water displaced by the body, viz. water of the bulk of *e f c d*. The body therefore, that it may remain in the position here represented, must have exactly the weight of the water which the immersed part of it displaces; and if it be lighter than this, it will rise higher, if heavier it will sink deeper.*"

The specific gravity of the human body is very nearly the same as that of water, and when the lungs are filled with air, (which is lighter than water,) the body will not sink. But to float upon the surface of water, it is necessary that a person should lie quietly, with the face upwards. By lifting up the head, as its weight in air is greater than in water, a downward impulse is given; and this is also the case with respect to throwing the limbs out of water. Thus the struggles of one who has accidentally fallen into deep water tend to make him sink; and the greater pressure of the liquid below the surface by compressing the air in the lungs, renders it more difficult for the body to rise.

Fig. 128.



367. The figure represents a glass jar nearly filled with water, and covered closely with a piece of Indian rubber. There are three figures of glass, which being hollow within and filled with air, are of less specific gravity than the water, and float on the surface. By pressing with the hand upon the elastic cover of the jar, a small portion of air which is between this cover and the surface of the water, is acted upon; this pressure forces the water through cavities in the feet of the glass figures into their bodies, and compresses the air within. Their increased specific gravity, causes them to sink. The cavity within the figure E, being greater than that within the figure D, the same pressure will force more water into E than into D, causing E to sink to a greater depth. For the same reason C does not sink as low as D. On raising the hand, as the pressure is then removed from the air [illegible] the cover of the jar and the water beneath [illegible] from the pressure, and the elastic air [illegible] out the water which had been forced [illegible] the surface.

368. *That bodies heavier than water sink in that fluid, may seem to contradict the assertion that* [illegible] *equal to downward pressure.* But [illegible] the same thing. Thus when a [illegible] ing the impulse of gravity, it [illegible] cannot do this with[illegible] own bulk: therefore it is [illegible]

* [illegible]

367. What [illegible] equal density? [illegible]

368. Weight and pressure [illegible] water?

equal to as much water, as is equal in magnitude **to the bulk of** the stone; but the weight of the *water* is less **than that of the *stone*,** therefore the force *pressing against it upwards,* **is less than its tendency** downwards, and consequently, the *pressure of* ***the water being less than the weight of the stone, the latter will sink.***

369. The specific gravity of a body is sometimes stated in *whole numbers* and *decimals*, sometimes in *fractions* only.—As it is often **important to be** very accurate in ascertaining the specific gravity of substances, and as the numbers 1, 2, 3, &c., would not in many instances express this difficulty, the weight of water may be considered not only as a *unit*, but as 10, 100, 1,000. Thus gold is a little more than 19 times heavier than water; this may be expressed by a vulgar fraction, $\frac{1}{4}$; or in decimals, either as 19.25, or 19.250, the fraction 25 being one fourth of a hundred, and 250 being one fourth of a thousand, the same proportion is expressed in both statements. If the weight of water is estimated as a unit, then the specific gravity of gold, (which is nineteen times and a quarter heavier than water,) should be expressed as $19\frac{1}{4}$; if the weight of water is estimated as 100, then the specific gravity of gold should be stated as 19.25, the decimal being the fraction of a hundred, &c. The specific gravity of pure alcohol is less than that of water; it is estimated as 797—that is, considering water as 1000.—The specific gravity of milk is somewhat greater than that of water, it being 1-032. Platina is the heaviest of all known substances; its specific gravity is 22, water being 1. The pure metals are the heaviest class of substances, their specific gravity being from 5 to 22. The *metallic ores* being a mixture of earth and other substances with the metals, are lighter than the pure metals, although usually above 4. The *precious stones*, as the diamond, emerald, &c., have a specific gravity between 3 and 4. *Common minerals* between 2 and 3. Some kinds of wood are a little heavier than water, as mahogany, which is 1,06; but generally wood is lighter than water. Cork has a specific gravity of .24. *Hydrogen gas*, the lightest of all known substances when compared to water, has a specific gravity of .00008, or eight one hundred thousandths.

Discovery of Specific Gravity.

370. Simple as appears the method of determining the specific gravity of bodies, it was not known until about 250 years before the Christian era.—Archimedes, a Philosopher of Sicily, surpassed all his predecessors in depth of research into the principles of mechanics and hydrostatics. He is celebrated for his treatises on mathematics, and for various philosophical discoveries and inventions. It is recorded in history, that Hiero, the king of Syracuse, having hired an artist to make for him a crown of pure gold, suspected the man had mixed with the gold given him for that purpose, some metal less valuable, but the crown weighed as much as the gold the king had furnished, and he knew of no method of detecting the fraud, if

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369. Modes of stating specific gravity. How is the specific gravity of gold expressed? Specific gravity of Alcohol. Of Milk. Of Platina. Of Metals in general. Of Metalic Ores. Of the precious stones and common minerals. Of Wood. Of Hydrogen Gas.

370. Time of the discovery of specific gravity. Suspicion of Hiero respecting his crown. His application to Archimedes. The Philosopher's perplexity. His observation while bathing. His experiments with pieces of gold and silver. With the king's crown. How was he able to ascertain the quantity of silver added?

there had been one, and applied to Archimedes for assistance. The object was, (without melting the crown in order to separate the mixed metals, if it were really composed of such,) to ascertain, without injuring the workmanship of the crown, its quantity of alloy. This could not be ascertained by any rule then known, and the Philosopher was much perplexed. One day, upon stepping into a full bath, he observed that a quantity of water flowed over which appeared equal to his own bulk, and that his weight seemed less in the water than out of it; he was struck with the idea that "*a body plunged into a liquid, loses a weight equal to that of a mass of the liquid of equal bulk,*" and leaping out of the bath, he ran through the streets shouting in the Greek language, "*eureka! eureka!*" "I have found it out, I have found it out." He afterwards proceeded to test the truth of his imagined discovery, and to apply it to the case under consideration. He took two masses, one of gold the other of silver, and each of equal weight to the crown; having filled a vessel with water, he first dipped into it the mass of silver, and accurately determined the quantity of water which flowed out; he then made a similar trial with the gold, and found that a less quantity had flowed out than before. Thus he established the fact, that the bulk of any mass of silver was greater than that of gold of the same weight. He then made the same experiment with the king's crown, and found that, though its weight was the same as the mass of silver and the mass of gold, it displaced less water than the silver, and more than the gold. Thus he ascertained that the crown was neither pure gold, nor pure silver. By determining the actual specific gravity, he was enabled to ascertain the exact quantity of silver, which the artist had added to the gold to make the weight the same as the original weight of gold delivered by the king.

LECTURE XXI.

ON LIQUIDS IN MOTION, OR HYDRAULICS.

371. The term *hydraulics*, (from two Greek words, *udor*, water, and *aulos*, a pipe,) was at first used to signify the motion of water in certain musical pipes, in use among the Greeks; it is now applied in a more general sense to *liquids in motion*, in distinction from *hydrostatics*, or *liquids at rest*. The popular use of the term hydraulics, is chiefly confined to the consideration of water-works, as pumps, fountains, engines, mills, and machines of various kinds, in which the power is derived from *water in motion*. Water can be set in motion by its own gravity; as when it descends from a higher to a lower level; in which case, it will seek the lowest situation; also by the pressure of condensed air, or by removing the pressure of the atmosphere, when it will rise above its natural level, and thus it may be forced to great heights.

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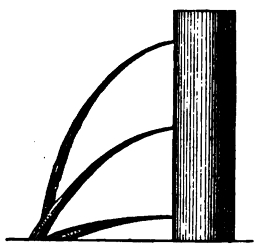
371. Definition of hydraulics. Popular use of the term. Causes of the motion of water.

372. The velocity with which water *spouts out* at an orifice in the side or the bottom of a vessel, is as the square root of the distance of the orifice below the surface of the water.

Fig. 129.



If, at the distance of one foot from the surface, the velocity is 1, because 1 is the square root of 1; another orifice four feet from the surface, would give the velocity of 2, because 2 is the square root of 4; and, at 9 feet deep, there would be a velocity of 3, because 3 is the square root of 9. Suppose a vessel (see Fig. 129,) discharging its contents at three orifices. The liquid from the upper spout being near the surface, receives but a slight pressure from the column above it, and flows with comparatively slight velocity; at the second spout, as there is a column of greater depth above it, the liquid is pressed out with greater velocity; and at the lowest spout, where the pressure is greatest, the velocity is also greatest.

The force of the pressure does not depend upon the width of the containing vessel, but upon the height of the column of fluid. (Art. 334.)

373. The liquid projecting from the side of a vessel describes *the curve of a parabola:* for two *forces* act upon the body in motion, viz., the *uniform pressure of the incumbent liquid*, and the *accelerated force of gravity;* in respect to which, liquids follow the same law as solids. The *random* or horizontal distance of the three spouts of water (represented at Fig. 129,) is greatest at the middle spout, and equal above and below. The *velocity of the lowest spout being greatest*, we might suppose the random would be so, if we did not reflect that this spout reaches the horizontal level sooner than those above it.

374. The velocity with which water issues from a spout, is *uniformly retarded as the surface of the column descends.* Here the mechanical law respecting liquids, is directly contrary to that of solid bodies falling freely by gravitation; but it corresponds to the law respecting solid bodies thrown upwards, for the force of pro-

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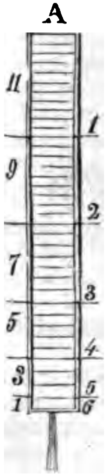
372. Velocity of spouting fluids. Velocity of spouting fluids at different distances from the surface. Why is the velocity greatest at the lowest spout, as represented in the figure?

373. Why does the projected liquid describe the curve of a parabola? Where is the *random* greatest in the three spouts represented in the figure?

374. Velocity of spouting fluids uniformly retarded. Spaces described by the descending columns.

jection is greater in proportion to the perpendicular height of the column, and this is constantly diminished by the flowing out of the liquid. The spaces described in equal times by the descending surface of the liquid column, are as the odd numbers, 1, 3, 5, 7, 9, &c., *taken backwards*; while, in solid bodies falling freely by gravitation, the spaces described are, as this series in an ascending order. Suppose a vessel filled with water be divided into 25 parts, and having at the bottom an orifice for letting off the liquid; if, in one minute, the surface descend through 9 of these parts, in the next minute it will descend through 7 parts, in the third minute 5, in the fourth 3, and in the fifth 1.

Fig. 130.



375. The *Clepsydra*, or water clock, is constructed on the principle we have just considered. If a cylindrical vessel of water be found to discharge its contents in a given time, by an orifice at the bottom, the sides of the vessel being divided by lines into equal spaces, these spaces become *divisions of time*. Thus, if the vessel A empties itself in six hours, divide it into 36 equal parts—for the first hour mark off 11 parts, for the second 9 parts, for the third 7 parts, for the fourth 5 parts, for the fifth 3 parts, and for the sixth hour 1 part.

There are some subjects, as the steam engine, pump, and syphon, which might, with propriety, be considered under the head of hydraulics or liquids in motion; but, in order fully to comprehend the principles on which they are constructed and on which their action depends, it is necessary to understand the nature and properties of air, which we are about to consider.

Synopsis.

376. 1st. *Hydrostatics* treats of the mechanical properties of non-elastic bodies, as water.

2d. Liquids press equally in all directions.

3d. A column of liquid presses in proportion to its perpendicular height, and the base of the vessel containing it.

4th. Specific gravity is the relative weight of equal bulks of different substances; *water* being made the standard of comparison.

5th. The science which teaches the laws of liquids in motion, is called *hydraulics*.

6th. The velocity of spouting fluids is as the square root of the depth of the orifice below the surface of the liquid.

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375. Clepsydra, or water clock. Subjects connected with hydraulics and pneumatics.

376. Synopsis of important principles in hydrostatics.

PART IV.

PNEUMATICS.

LECTURE XXII.

AERIFORM BODIES.—ATMOSPHERE.—THE AIR-PUMP.

377. The Greeks, under the term *pneuma*, included air, vapors, and gases of all kinds with which they were acquainted, and also the soul or spirit of man. From *pneuma* is derived *pneumatics*, or that science which treats of the mechanical properties of *elastic* or *aeriform liquids*. It is chiefly the phenomena of atmospheric air that we are now to investigate.

378. Every one possessing any knowledge of chemistry knows that there are, in nature, several kinds of gas; that these gases, by their union with each other, form water and air; that with metals they form ores in various proportions, and that they exist in all animal, vegetable, and mineral substances. But with gases, strictly so called, we have, in Natural Philosophy, little to do; as their part in the economy of nature is, chiefly, to be detected by the minute analyses, and careful experiments of the chemist. *Aeriform** *bodies* are *vapors*, *atmospheric air*, and *gases*. *Vapors* are elastic fluids formed from liquid or solid bodies, by means of heat, and which, on losing heat, are again condensed into a liquid or a solid state. *Steam* is vapor; it being nothing more than particles of water, driven to a greater distance by the repulsive power of heat, and thus rendered more rare and elastic. The same particles, by the loss of heat, may again exist in the form of water, or by los-

* The term *aeriform* is from the Greek *aer*, signifying air or spirit.

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377. Definition of pneumatics.

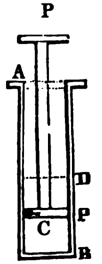
378. Gases. Aeriform bodies. Vapors. Are vapors permanently elastic fluids?

ing still more heat, may become ice. Because steam may thus be *condensed* into a liquid and even a solid form, it is not considered as a *permanently* elastic fluid.

379. The gases and atmospheric air never exist in either a liquid or solid form, except when combined with other substances; nor is it easy, by any ordinary degree of cold or pressure, to bring them into these states. They are, therefore, called *permanently elastic fluids.*

380. A substance to be elastic must be compressible, and at the same time possess the power of expanding to its original bulk when the pressure is removed. "Let A B be a cylinder, in which the piston P moves, air tight, and suppose that a small portion, as *a cubic inch* of atmospheric air in its common state, be contained between the piston and the bottom of the cylinder; suppose the piston now drawn upwards, (as at C,) so as to increase the space below it to *two* cubic inches.—The air will not continue to fill one cubic inch, leaving the other cubic inch unoccupied, as would be the case if a solid or liquid had been beneath the piston in the first instance; but it will expand, or dilate, until it spreads itself through the two cubic inches, so that every part of this space, however small, will be found occupied by air.—Again, suppose the piston further elevated, (as at D,) so that the space below it shall amount to *three* cubic inches; the air will still further expand, and will spread itself through every part of the increased space; and the effect would continue to be produced, to whatever extent the space might be increased through which air is at liberty to circulate."*

Fig. 131.



381. Atmospheric air is a *permanently elastic* fluid or gas, composed of two kinds of gas, *oxygen* and *nitrogen.* The ancients considered common air as a simple element; but chemical analysis has shown its compound nature.

382. As the mechanical laws and properties of *liquids* are, in *hydrostatics*, chiefly illustrated by a reference to *water* as a representative of the whole class of non-elastic fluids, so the mechanical laws and properties of *aeriform bodies*, or elastic fluids, are exemplified in *pneumatics* by a reference to *common air.*

283. The *solid portion of the globe*, being most influenced by gravity and cohesive attraction, occupies the lowest place, forming the great centre of the whole mass. Above this, floating within cavities, and filling up the inequalities of the solid substances, is the *liquid body* which constitutes oceans, seas, lakes,

* Lardner's Treatise on Pneumatics.

379. Why gases and air are called *permanently* elastic fluids.
380. Experiment to show the elasticity of air.
381. Component parts of common air.
382. Common air considered as representing the class of aeriform bodies.
383. Lowest portion of the globe. Substance which fills up the cavities of the earth. Substance which envelops the globe. Atmospheric ocean. Its use and importance. Analogies between the aqueous and atmospheric oceans.

and rivers. A third substance, less influenced by gravity, and not affected by cohesion, envelops the whole; it may be considered an *atmospheric ocean* of nearly fifty miles in depth. In this fluid man and animals are fitted to exist, as the aquatic tribes are adapted to their watery element; fresh air being as necessary to the former, as water is to the latter. The fish does not die sooner when taken out of water, than does the bird or insect which is confined in a vessel exhausted of air. The fish swims in the water by means of fins, and the bird and the insect fly in the air by means of wings. Man, by his muscular strength, treads upon the solid earth; but he moves in an ocean of air, and, every minute, consumes in respiration, not less than a gallon of this element.* There are plants which grow only when surrounded and fed by water, but most of the vegetable tribes require the constant agency of air, in order to support their vital functions. Gentle currents of water bear upon their smooth surfaces the light bodies which float there; but the torrent hurries onward carrying away rocks and embankments, and destroying in a moment the proudest works of art. Air, which now gently wafts the floating gossamer, when it appears in the terrific form of the whirlwind, uproots the oak of the forest, prostrating, alike, the works of nature and of art.

The Atmosphere.

384. The *Atmosphere* which surrounds the globe consists of *air*, with the *clouds*, and *other vapors* which float in it. It *revolves* with the earth, around the sun. It *reflects the sun's rays upon the earth;* but it is proved, that this power of reflection does not extend above the *height of forty five miles*; therefore, it is supposed that the atmosphere does not extend much beyond that height above the earth. It is not of equal *density* in all its parts; as the lower portions sustain the pressure of those above, they are consequently more dense. The greater the elevation, the *lighter* or more rare is the atmosphere. The air is also *colder* in proportion as we ascend into the *higher* regions; for it is not heated by the rays of the sun which it transmits to the earth, as gaseous fluids permit radiant matter to pass freely through them, without any absorption. Air receives heat from the earth, and by actual contact with such matter as contains it; that is, the stratum of air next the earth receives a portion of heat, which in turn communicates heat to the air above it, and so on; the quantity of heat

* We here use the term element in its *popular* sense, and not according to the laws of science, which confine it to substances that are simple, or not capable of decomposition.

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384. Atmosphere, its component parts, revolution and height. Its density. *Why the* air near the earth is warmest.

communicated, decreasing, in proportion as the distance from the earth increases. For every 300 feet of elevation, the temperature of the air is found to be one degree lower, or the climate one degree colder.

Air is Material.

385. Matter is that which is perceived by our senses. We do not see the air which immediately surrounds us, because it is transparent; but we *feel* it in the breeze, and we *hear* it, in all the sounds which fall upon the ear. Its existence is also manifested to our senses in a great variety of common appearances, and in experiments which may be almost infinitely multiplied. Air, though generally considered as visible, is not so; we do not indeed see it in the apartment where we sit, but when we look abroad upon the concave firmament, illuminated by light, we see an *azure-colored vault.* This color is that of the mass of atmosphere, through which we behold the celestial luminaries. The distant mountain and the ocean have the same hue, not because this is their own color, but that of the medium through which they are seen. A small quantity of sea-water scarcely appears colored, but the deep sea has a decided green color. These phenomena may be easily explained; a *small* portion of sea-water, reflects to the eye so little color as not to be perceptible, while *large masses* throw off color in such quantities as to make an impression upon the eye.

386. *Extension* and *impenetrability* have been stated to be essential properties of matter. The *extension of air* is to be perceived on all sides, we cannot draw a breath without its agency, and were we for a few minutes to be deprived of it, suffocation and death must ensue. The *impenetrability* of air, (though this may seem at first doubtful,) is not less certain than that of iron and wood. No other body can exist in the same space which is occupied by air, any more than one *solid* body can occupy the same space which is filled by another solid body.

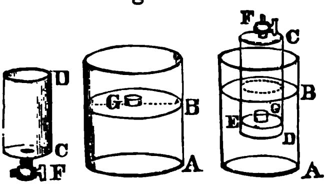
Fig. 132.

387. Plunge a tumbler perpendicularly into a glass vessel containing water; the water will not rise to fill the tumbler, because the upward pressure of the fluid is resisted by the confined air, which has no chance of escape. But if, instead of plunging the tumbler perpendicularly, it be held a little inclining to one side, the air within will escape in large bubbles, and water will rise to fill the inverted tumbler.

388. Let B A be a glass vessel containing water to the level B, and let D C be an empty glass jar, having

385. Proof that air is material. Air not invisible.
386. Extension a property of air.
387. Experiment to prove the impenetrability of air. Exp.
388. Experiment 2.

Fig. 133.



a short tube furnished with a stop-cock at F. Let a cork float on the surface of the water, at G, and let the jar C D, having the stop-cock closed, be inverted over the cork G, and the mouth, D, be pressed into the water in the right-hand vessel A B. If the air in C D were capable of permitting the entrance of another body into the space in which it is present, the water in A B, would rise in C D, and stand in the same level in the latter vessel as in the former. But the water does not enter the inverted vessel, except at a very limited height, as will be seen by the cork floating on the surface. The air which occupies the space C E excludes the water. This may be proved by opening the stop-cock F, when the air which opposed the rise of the water will escape, and the water, by its upward pressure will ascend to fill the vacant space. As air is compressible, the water rises in the vessel C D, to the height E, in consequence of the original bulk of the air which filled C D, being reduced by pressure.

The Air-pump.

389. One of the most important articles of a philosophical apparatus, is the air-pump. It shews the effect of the loss of air upon animals and vegetables, as under the exhausted receiver, both die. By experiments with the air-pump we learn that without air there can be no sound, for a bell under the exhausted receiver of an air-pump cannot be made to ring—we see that a piece of lead and a feather, but for the resistance of the air, would fall in the same time from equal heights, or, that both are alike attracted by gravity—we see that a very small portion of air in a bladder, expands when the pressure of air around it is removed, even to the bursting of the bladder which contains it;—and that a shriveled apple under the exhausted receiver, by the expansion of the air contained within it, becomes plump and smooth.

390. *Terms used in explaining the construction of the air-pump.*

Valve;—this is merely a little door or lid, which permits a fluid to pass in one direction, and prevents its return. On the lower board of a common bellows is a large aperture, covered within, by a stiff piece of leather, commonly called the clapper. This covering, which is moveable on a hinge, is a *valve*, capable of being opened inwardly by the slightest pressure. On raising the upper board of the bellows, the cavity within is suddenly enlarged, and the valve is opened by the pressure of the external air rushing in to fill the vacuum. But the air cannot return by the same aper-

389. Some of the phenomena exhibited by the air-pump.

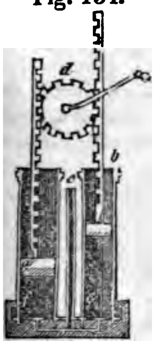
390. Valve. How does the air enter and escape in a common bellows? *Valve* of the air-pump. Describe the piston and cylinder. Piston-rod.

ture at which it entered, because it presses upon the valve and keeps it closed. On depressing the upper board of the bellows, a stream of condensed air rushes out at the only opening it can find, viz., the nozle. The reason why an aperture in the leathern sides of a bellows destroys its utility is, that the air finding other vent, issues but feebly through the nozle.

The valve of the air-pump usually consists of a strip of oiled silk, tied over a small orifice. The air pressing *outwards*, raises this valve and escapes.

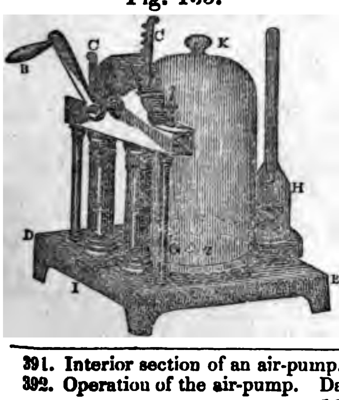
Piston and *cylinder*;—The piston is a stopper, or *moveable* plug fitted to a hollow cylinder, called a *barrel*. The piston is moved by means of a handle, called the *piston-rod*. It is covered with leather, and oiled, so as to slide up and down the barrel air-tight, or without allowing air to pass by its sides.

Fig. 134.



391. We have, in the figure, an interior section of an air-pump; *a b* are air-tight pistons working, each in its cylinder, by means of the piston-rods *p p*; *c* is the space under the receiver from which air is to be exhausted; *d*, a wheel and crank which, by turning, alternately raises and depresses the pistons; *e*, a valve which, when the piston *b* is raised and a vacuum thus formed below, is forced upwards, and admits air from the receiver through the cavity *c*: this air rushes out by opening a valve in the piston *b*; *f* is a valve similar to *e*, and which, when the piston *a* is raised, admits the passage of a portion of air from the cavity *c*; this air issues out of the air-pump by raising the piston-valve at *a*.

Fig. 135.



392. The figure represents what is commonly called a *double-barrel air-pump*, having *two cylinders* or *barrels*. The use of two cylinders is to quicken the operation, for while the piston of one is rising, that of the other is falling. Each piston when elevated, by the closing of the valve below, and the opening of its own valve, draws a portion of air from the receiver. A A are the *brass cylinders* in which

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391. Interior section of an air-pump.
392. Operation of the air-pump. Darwin's description of the air-pump.

the pistons work. C C are the *toothed piston handles*, adapted to corresponding teeth in the pinion-wheel. B is the *crank* by which the wheel is turned, and which in its motion alternately raises and depresses each piston. K is the *bell-glass receiver* from which the air is to be exhausted. D E is the *mahogany frame* which supports the whole. At I is a *screw*, by the turning of which the external air is admitted. H is a *barometer-gauge* connected with the receiver. The receiver should be so closely fitted to the brass plate as to exclude the entrance of air.

The philosophic poet, Dr. Darwin, thus describes the operation of the air-pump:

———" Now, as in brazen pumps the *pistons* move,
The *membrane valve* sustains the weight above,
Stroke follows stroke, the gelid vapor falls,
And misty dew-drops dim the crystal walls;
Rare and more rare expands the fluid thin,
And silence dwells with vacancy within."

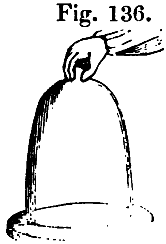
The "vapor" and "dew-drops" alluded to by the poet, are aqueous particles, of which the air usually contains a portion, and which are set free by the sudden expansion of the air in the receiver, causing a mist on its inner side. The allusion to silence refers to the fact, that in "vacancy," or without air, there can be no sound.

LECTURE XXIII.

THE PROPERTIES OF AIR.

393. The properties of air, demonstrated by means of the air-pump, are *weight*, *elasticity*, *pressure*, and *condensation*.

Fig. 136.



Weight of Air.

394. Exp. 1st. The air being exhausted from the receiver of an air-pump, it will be held fast by the pressure of the external air. On turning the screw at I, (Fig. 135,) air rushes in, and the receiver may be lifted up with ease, because the pressure of the air within, balances that of the air without.

Exp. 2d. If a small receiver be placed under

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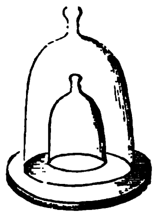
393. Properties of air demonstrated by the air-pump.
394. Experiments for proving the weight of air. Exp. 1. Exp. 2. Exp 3. Exp. 4.

Fig. 137.



a larger, and both be exhausted, the larger receiver will be held fast, while the smaller one may be easily moved. This is, because the large receiver, having no air within, is weighed down by the external air, while the small one is free from the pressure of air, without and within.

Exp. 3d. If a glass receiver, open at the top, be covered tight with a piece of bladder, and then fixed upon the plate of the air-pump and exhausted of air, the bladder will burst with a loud noise. The weight of the air above, which is not counteracted by any pressure below, produces this effect.

Exp. 4th. A bottle uncorked placed within a receiver, and exhausted of air, will be found to weigh less than when full of air. A wine quart of air is proved to weigh eighteen grains.

395. The *specific gravity* of air is about 800 times less than that of water. In explaining the construction and uses of the barometer, we shall have occasion to make some further remarks on the weight of air, especially of the whole atmospheric column.

Elasticity of Air.

396. Air is *perfectly elastic*, since, when compressed, it tends to restore itself with a force equal to that by which it is compressed. Air is considered as *permanently* elastic, because no force has yet been able to bring it into a liquid or solid form.

Exp. 1st. A bladder which *seems* empty, on being closely stopped at the neck and placed under the receiver of an air-pump, will, when the receiver is exhausted, expand by the elasticity of the small portion of air within. A very small quantity of air, when released from external pressure, will expand to an extent which appears almost unlimited; on letting air into the receiver, the bladder thus distended will shrink up again, and its sides be pressed together by the weight of the external air.

Exp. 2d. Let a bladder with the neck tied, be put into a wooden box, with a weight of several pounds upon the lid, and this box be placed under a receiver; on exhausting the receiver, the air in the bladder, by its elastic spring, will raise the lid of the box with the weight upon it.

Ex. 3d. "The effect of air upon the lungs of animals, is exemplified by a simple instrument called the *lungs-glass*. This consists of a glass vessel into which is screwed a brass tube, on the end of which is tied a bladder containing a small quantity of

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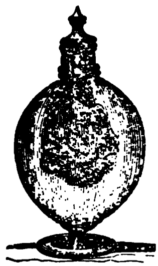
395. Specific gravity of air.

396. Air *perfectly* and *permanently* elastic. Experiments to show the elasticity of air. Exp. 1. Exp. 2. Exp. 3. The lungs-glass. Exp. 4.

air. When the glass is placed under the receiver, and the action of the pump commences, the air within the bladder will issue out at the tube, while that between the bladder and the glass, having no way to escape, will exert its elasticity and shrivel the bladder (as seen in the figure); but on re-admitting air into the receiver, a portion will enter the bladder and inflate it to its former size. The same effect is produced upon the lungs of an animal when placed under a receiver, and the air exhausted: the air in the lungs is drawn out, that in the cavity of the chest is expanded, the lungs are shriveled up, their action ceases, and death is the certain consequence unless the air be instantly admitted into the receiver, in which case the lungs are again inflated and the animal breathes."

Fig. 138.



Exp. 4th. A fresh egg contains at its large end a bubble of air; if a small hole be made at the opposite end of the egg placed under a receiver, upon exhausting the air, the contents of the egg will be forced out of the shell by the elastic spring of the bubble of air within.

397. The peculiar, gurgling sound which takes place on decanting liquids, arises from the elastic pressure of the atmosphere, which forces air into the interior of the bottle. At first, the bottle being filled with the liquid, no air can enter, but as soon as a portion of the liquid flows off, an empty space is formed within the bottle; a bubble of air, forcing its way through the liquid in the neck, rushes to fill its vacuum, and this causes the gurgling sound, which will continue, until such a portion of the liquid has passed out as will allow the remainder to flow without completely filling the neck of the bottle. The report which accompanies the uncorking of certain liquors, is owing to the elastic force of the air which was condensed within the bottle. When liquor is bottled, a small space left near the top of the bottle is filled with air; on driving in the cork, this air is condensed, the same quantity being made to occupy as much less space as the cork fills. The nature of some liquids is to produce, when bottled, a quantity of gas, and this often presses with such force as to drive out the cork, or, if this is secured, to burst the bottle. The froth which appears on pouring out bottled beer or porter, the effervescence of soda water, the sparkling of cider and champaigne wine, &c. are owing to the pressure of condensed air, which appears in the form of little bubbles.

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397. Cause of the sound in decanting liquids, uncorking bottles of beer, &c. Frothing, effervescence, and sparkling of liquors.

Pressure of the Air.

398. From the *weight* and *elasticity* of the air, arises its *pressure*; and experiments which prove the two former properties, equally demonstrate the latter. But for the sake of greater clearness, we prefer to consider these analogous properties under distinct heads.

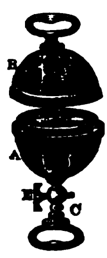
399. If, as has been ascertained, one quart of air weighs eighteen grains, the weight of a column of air, extending nearly fifty miles above us, must be very great; and, consequently, its pressure, which is in proportion to its height, must also be great. If the human body was subjected to the pressure of a column of air directly over it, without any counteracting pressure from *within* and *around*, the incumbent weight would be insupportable.

Fig. 139.

400. Let a glass having an opening at the top, be placed over the plate of the air-pump, and let a person lay his open hand upon the top of the vessel so as to cover it closely; on turning the handle of the air-pump a few times, the hand will be pressed down with such force as to render it impossible to raise it, and much pain will be felt. The pressure under the hand being removed, by exhausting the air from within the glass, the pressure from above is thus left to operate without any counteracting force. The pain which is experienced will serve to show, in some degree, what would be the effect upon the whole body, if all but the downward pressure were removed.

401. The actual amount of pressure of a column of air upon every square inch, is demonstrated by an experiment with a simple apparatus called the *Magdeburgh hemispheres.** This consists of two hollow hemispheres of brass, A B, made to fit so closely as to form an air-tight globe. In the lower part, C, is a stop-cock E, and a tube which screws into the plate of the air-pump; when the air is exhausted within the globe, the stop-cock being turned to prevent the return of the air, the apparatus may be taken from the air-pump, and the handle C screwed on to the tube. Before the air was exhausted from the interior of the globe, the two parts could be separated with ease, but when subjected only to external pressure, they adhere with much force. Under an exhausted receiver, the hemispheres

Fig. 140.

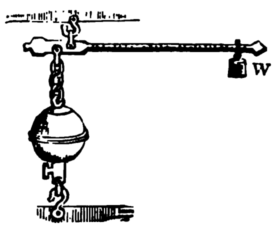


* This experiment was one of the first which drew the attention of man-

398. What causes the pressure of air?
399. How can the human body endure the downward pressure of the air?
400. Experiment for proving the pressure of air.
401. Experiment with the Magdeburgh hemispheres.

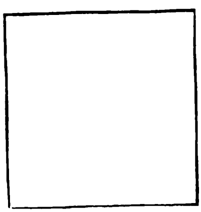
thus exhausted, may easily be separated, because the external, as well as the internal pressure of air is removed. By means of a steelyard hooked to a ring at the top of the globe, it may be proved what weight is neccessary to overcome this pressure of the atmosphere; for when the weight, W, is at a certain point on the arm of the steelyard, the upper hemisphere is lifted up. Suppose the mouth of the hemisphere contains 12 square inches, and that it requires a weight of 180 pounds to raise the upper one; if we divide the weight 180, by 12, the number of inches, the quotient is 15 pounds, which is the pressure on every square inch of surface.—That is, a column of air reaching to the top of the atmosphere, and whose base is a square inch, weighs 15 pounds.

Fig. 141.



402. The figure represents a square inch; the inclosed space must therefore sustain the pressure of fifteen pounds. Every person must then sustain a pressure of air equal to 15 times as many pounds as there are square inches on the surface of that body. Suppose the surface of a man's body to measure 2000 square inches, the force of the atmosphere pressing on that surface would be equal to 30,000 pounds. But the air being so uniformly distributed, within, without, and on all sides, we are not sensible of this pressure.

Fig. 142.



403. Boys, sometimes in their sports, and without knowing it, make philosophical experiments; thus the *leather-sucker* illustrates the pressure of air, arising from the joint effect of elasticity and weight. This is nothing more than a piece of leather having a cord attached to its center. On moistening this, and applying its surface to any heavy body, as a stone or block of wood, it will adhere so firmly that the body may be raised by the string. This

kind to the mechanical properties of air. The inventor of the apparatus was Otto de Güericke, of Magdeburgh in Germany, who had hemispheres made of a foot in diameter. It is said that at a public exhibition of his apparatus, six horses of the emperor were unable to pull the hemisphere asunder. There being no air-pump at this period, (about 1657,) the inventor was obliged to exhaust the hemispheres of air, by the slow process of filling them with water, and then extracting the water by means of an exhausting syringe, or common pump, applied at the tube.

402. Pressure on one inch of surface. Amount of pressure on the human body.
403. The leather-sucker. Flies walking on ceilings and window-panes.

Fig. 143.

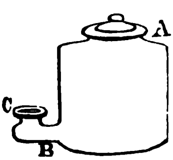
effect arises from the exclusion of the air between the leather and the stone. The air pressing with a weight of nearly fifteen pounds upon a square inch, it follows that witn a square inch of leather a stone of nearly fifteen pounds weight may be raised.

The power of flies and some other insects, to walk on smooth ceilings with the feet upwards, or upon perpendicular panes of glass, depends on the same principle as the action of the sucker. Their feet are so constructed as to be capable of exhausting the air under their soles. There is an animal of the lizard kind which can thus walk with its back downwards, and the walrus and seal walk on walls of smooth ice.

404. "Breathing is, in part, the effect of the pressure and elasticity of air. When we draw in the breath, we first make an enlarged space in the chest. The pressure of the external atmosphere then forces air into this space so as to fill it. By muscular action, the lungs are next compressed, so as to give to this air a greater elasticity than is allowed by the pressure of the external atmosphere. By the force of this elasticity, air is propelled, and escapes by the mouth and nose. It is obvious, therefore, that the air enters the lungs, not by any direct act of these organs upon it, but by the weight of the atmosphere forcing it into an empty space, and that it is expired by the action of the lungs conpressing it.—The action of the common bellows is precisely similar, except that the aperture at which the air is drawn in, is different from that at which it is expelled."*

405. The figure represents an ink-bottle constructed upon the principle of *atmospheric pressure*. It is evident that were the top at A open, the liquid would flow out at the tube C, until that in the body A B were brought to the level of C.—But the body is entirely close, while the tube C is open. The bottle is filled, by being placed in an inclined position and pouring in ink at C. Let the bottle now be placed upright as in the figure, and the pressure of the atmosphere at the orifice C, will prevent the liquid from running out. We now perceive why it is necessary to make an opening, called a vent-hole, at the top of a cask, that the liquor within may flow out at an orifice at the side or bottom. The pressure of the external air acting upon the liquor at the orifice would prevent

Fig. 144.



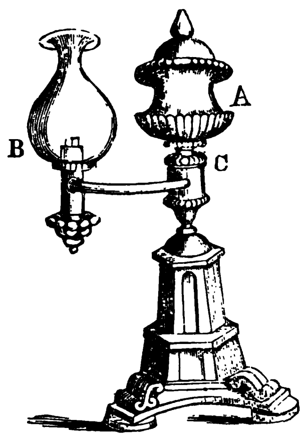
* Lardner's Treatise on Pneumatics.

404. What effect has air upon breathing?

405. Scientific ink-bottle. Why are casks and tea-pots furnished with a vent-hole? Fountain lamp.

its flowing out, unless this pressure were counterbalanced by atmospheric pressure within the cask, in which case the liquor descends by its own weight. A small hole in the top of a tea-kettle would prevent the water, when boiling, from running out at the spout. It is common for house-wives when the " tea-kettle" boils, to raise the lid a little on the side, which has the same effect.—Tea and coffee pots when closed tight, will not admit liquids to pass freely out at their spouts, unless the vent hole is made in the side.

Fig. 145.



The influence of atmospheric pressure in restraining the flow of a liquid, is also seen in the argand or *fountain lamp*, where the oil is in a part of the lamp A, higher than the flame B. The top A being filled with oil, is screwed upon the body of the lamp, at C. The oil descending and passing through the horizontal tube which connects B to C, rises into the wick and thus supplies the flame, while it is restrained from flowing out by the pressure of the air upon the opening at the chimney.

406. *The pressure of air is as the depth.* As the bottom of a lake or sea supports the whole mass of water above it, so the part of the atmosphere next the earth supports the whole mass of air. The lower portions of the air sustaining the pressure of those above, are, therefore, more dense. Air upon high mountains is, for the same reason, lighter than in lower situations.

LECTURE XXIV.

THE CONDENSATION OF AIR.—CONDENSING SYRINGE.—ARTIFICIAL FOUNTAINS.—AIR-GUN.—DIVING-BELL.

The Condensation of Air.

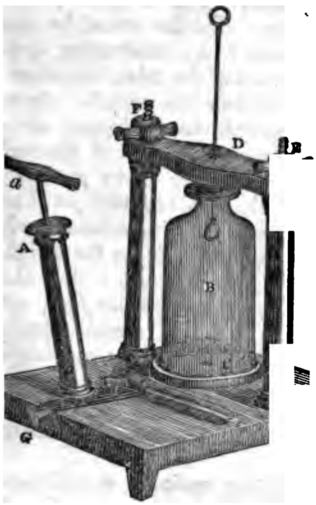
407. Air from its elastic properties may be greatly condensed, or forced by pressure into a smaller space than that which it natu-

406. Pressure of air proportioned to its depth.
407. To what is the elasticity of condensed air equal?

y occupies. *The elasticity of condensed air is equal to the ce which compresses it.*

08. The *condenser* is a machine which exhibits the properties of *condensed air.*

Fig. 146.



At A is a brass barrel containing a piston, with a valve *opening downwards.* On raising the handle (*a*) of the piston, the air presses through the valve, and is forced into a tube communicating with the receiver B, which in order to sustain the internal pressure, must be made of very thick and strong glass. At every stroke of the piston, more air is thrown into the receiver. This is held down upon the plate C, by the cross piece D, and by the screws F E. By turning the stop-cock G, the ensed air is suffered to escape.

9. The operation of this machine is the reverse of that of ir-pump; in working the latter, *we pump air out* of the re-r, in the former, we *press air in.* In the use of the air-, we cause air to expand and become more rare, in that of ondenser we continually add to its density. The receiver of ndenser may be compared to that of a wool-sack, at first with wool lying loosely, as in its natural state, and then led with successive portions, until it is made to contain a it many times greater than at first. But compressible as is, it is far less so than air, *which can be lessened in bulk, to ree to which no limits can be assigned, but the want of strength apparatus used, and of force in the power applied.*

). A bell emits a much heavier sound when rung in condenhan in common air.

. Condenser.

. Comparison between the air-pump and condenser. To what may ceiver of a condenser be compared?

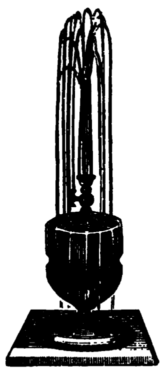
. What effect has condensed air upon sound? How may a bottle be n by condensed air?

13

A thin bottle containing common air and closely corked, will be broken inwards, by the pressure of condensed air.

411. The elastic power of condensed air may be shown in the production of *artificial fountains.* Let a strong vessel of brass or copper be furnished with the stop-cock inserted at the top, from which a tube proceeds nearly to the bottom. Let the vessel be partly filled with water, and with a condensing syringe fitted to the upper part of the tube, introduce an extra quantity of air into the vessel. As soon as a stop-cock is turned, the condensed air acting on the water beneath, forces it through a tube which is inserted in the lower part of the vessel, and thus produces a beautiful *jet d'eau.** The greater the quantity of air condensed within this fountain, the greater will be the height to which the water is forced, because the *elastic power of air, is in proportion to the force which compresses it.* If a vessel of similar construction to that represented in the figure, and containing common air, be placed under the tall receiver of an air-pump, when the surrounding air is rarefied, the jet will rise, the same as in the case of condensing the air within.

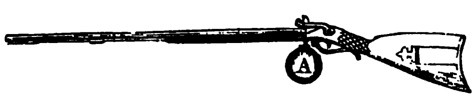
Fig. 147.



The Geysers of Iceland are spouting springs, occasioned by the force of confined air, or gas, acting upon the water; this force is immense, since not only water, but large stones are thrown by it to the height of more than two hundred feet.

412. The *air-gun* affords a striking proof of the force of condensed air. This, in its general appearance, is very like a common gun, with the addition of a metallic ball, A; into this ball, which is furnished with a valve opening inwards, the air is forced by means of a condensing syringe, after which the ball is screwed on to the gun, below the lock, as appears in the figure. The gun

Fig. 148.



* A French phrase signifying an upward spout of water.

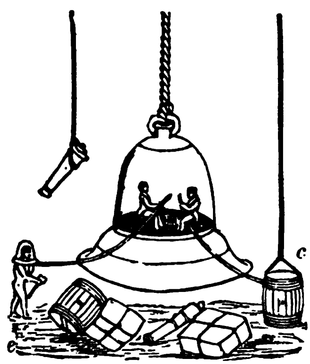
411. Artificial fountains. The Geysers.
412. Air-gun.

is now loaded with a bullet, and the lock being sprung, acts upon a pin which opens a valve; the condensed air now rushes into the barrel of the gun, and by its sudden expansion, forces out the bullet.

413. The diving-bell exhibits an interesting illustration of the *compressibility*, *elasticity*, and *impenetrability* of air.

The diving-bell, is a large, open mouthed vessel, capable of containing one or more persons. By means of this machine, men are able to descend to considerable depths in the ocean, for the purpose of saving valuables from the wrecks of vessels, and of pursuing works of submarine architecture, such as laying the foundation for harbors and light-houses. The diving-bell is also used in pearl, and coral fisheries.

Fig. 149.



414. When first introduced into use, it was made of copper, and constructed in the form of a bell, the height being about eight feet, the diameter of the bottom five feet, and that of the top three feet; it contained about eight hogsheads. Light was admitted by strong spherical glasses, at the top, as in the cabins of vessels. An English poet before the invention of the diving-bell, prophetically exclaimed;—

——" Lo! Britain's sons shall guide
Huge sea-balloons beneath the tossing tide;
The *diving castles*, roof'd with spheric glass,
Ribb'd with strong oak, and barr'd with bolts and brass."

415. When the diving-bell is first let down into the water, it is full of air, but the pressure of the surrounding water, (which pressure increases with the depth,) acting upon the inclosed elastic air, compresses its bulk, and the liquid rises proportionally in the bell.

As a column of water 34 feet deep, causes a pressure equal to a whole column of the atmosphere, it follows that at this depth, the air in the bell is under a pressure equal to *two atmospheres*, viz., that of the whole atmospheric column; and the

413. What properties of air are illustrated by the diving-bell? Why does not water completely fill the diving-bell? The uses of the diving-bell.

414. Explain the construction of the diving-bell. What condenses the air in the bell?

415. Pressure at the depth of thirty-four feet. When is the air in the bell twice as dense as common air? What renders the air in the bell impure? How is the impure air let off? How is the diver supplied with fresh air?

column of thirty-four feet of water; the air is, therefore, here condensed into half its original bulk because a weight of two atmospheres is found to diminish the bulk of air to one half, of three atmospheres to one third, or of fifty atmospheres, to one fifteenth of its former bulk. As the depth of the water, and consequently the pressure increases, the air will be proportionally condensed, and the water will rise in the bell. When the air is twice as dense as air at the surface of the earth, the diver at each inspiration of the breath, will receive twice as much air into the lungs as when breathing common air.

In breathing, the diver is constantly throwing from his lungs a large portion of a gas, which is fatal to animal life.* This impure air being more rarefied than the air within the bell, rises, and is let off by opening a stop-cock at the top of the machine. In order to supply the diver with fresh air, barrels of air having leaden weights attached to them, are let down, (see *c*, Fig. 149,) and by means of connecting tubes they convey air into the bell. At *e* is a man walking at a little distance from the bell, to recover some bales of goods which had been thrown overboard from a vessel in distress. He wears on his head a leaden cap, having glasses in front to admit light, and breathes by means of air from the flexible tube connected with the bell. In this manner, the divers sometimes go a hundred yards from their bell.

Fig. 150.

The bell is furnished with seats for the workmen, and with tools of various kinds.

416. A machine of later construction, is considered an improvement upon the diving bell. *a*, (Fig. 150,) is a bent tube connected with a forcing air-pump, *d*, by means of which a constant supply of fresh air is sent down from a ship above; this air the diver can obtain by turning the stop-cock. At the bottom, are heavy balls of lead, to sink the machine vertically. Men in the ship above, raise the machine by means of ropes and fixed pulleys. When the divers wish to be drawn up, they pull a rope which rings a bell; when they want to convey information to those above, they write upon a sheet of lead which they send up, by pulling a cord moving over a pulley fixed to the ship.

* Carbonic acid gas.

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416. Describe the diving-bell represented in Figure 149.

LECTURE XXV.

BAROMETER.—EFFECT OF HEAT UPON AIR.

417. The ancients had no conception that the *pressure* of air caused it to penetrate every crevice and cavity on the surface of the earth; they said, therefore, it was because *nature abhorred a vacuum*, that where there was nothing else, there was sure to be air. They perceived that when a solid or liquid was removed, the surrounding air immediately rushed in to take its place; but instead of referring this fact to the simple and obvious principle of atmospheric pressure, they seemed resolutely to shut their eyes to the light of truth, and rested satisfied with their absurd hypothesis, that nature abhorred a vacuum. The effect of *suction* with the mouth, is, probably, one of the first ways in which the subject of atmospheric pressure forced itself upon the observation of mankind. When one end of a tube is immersed in a liquid, and the other placed in the mouth, the air may be withdrawn from this tube by inhaling, and water will rush into the tube as fast as the air leaves it. Ancient philosophers could not see in this, any evidence of atmospheric pressure, but, like children, who attempt to account for what they do not understand, they said, "we suppose this takes place because nature being uneasy with a vacuum, makes the water rise to fill it." This kind of reasoning, though fatal to the progress of true physical science, did not prevent men from constructing common pumps of various kinds, in such a manner that they answered the desired purposes. About two hundred years ago, as some engineers of the Grand Duke of Florence attempted to raise water, by means of a common pump, to the height of fifty or sixty feet, they perceived that the water, after mounting about *thirty-four feet*, would rise no higher. They communicated this fact to Galileo, the most celebrated philosopher of that day. After various experiments, he became satisfied that this was a universal law of nature, and that the rise of water to a certain height in pumps exhausted of air, was neither owing to *nature's horror of a vacuum*, nor to the *power of suction*, (as some had vaguely suggested,) but to *atmospheric pressure*.

418. Torricelli, a pupil of Galileo, carried his inquiries farther. As a column of thirty-four feet of water is equivalent to a column

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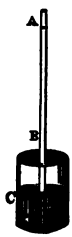
417. Ignorance of the ancients respecting atmospheric pressure. Their hypothesis Attempts to raise water in pumps more than thirty-four feet. Discovery of Galileo.

418. Torricelli's experiments. What column of water and what of quicksilver, are equal in weight to a column of the atmosphere?

of air extending upward from the surface of the earth through the whole region of the atmosphere, why, he inquired, may not a column of any other fluid, of a given height, balance a column of air? As quicksilver is nearly fourteen times heavier than water, he imagined that a column of that fluid, of one fourteenth part the height of a column of water thirty-four feet high, might be equal to the pressure of air. He therefore filled with quicksilver, a glass tube, A B, of about three feet in length, closed at one end, and open at the other, and placing the open end of the tube in a basin of quicksilver, C, he found that the fluid in the tube fell a little, but remained suspended at about 20 or 30 inches, leaving a space at the top of the tube, above the quicksilver, which was a perfect vacuum. By dividing 34 feet, (408 inches,) the height of water which the pressure of the atmosphere will support, by 14, (because quicksilver is 14 times heavier than water,) the quotient 29, shows that a column of quicksilver of the height of 29 inches, equals in weight a column of water of 34 feet.

Fig. 151.



419. But even after the experiments of Torricelli, though it was admitted that the quicksilver was suspended in the tube by the pressure of the surrounding air, it was not observed that the height of the column of quicksilver was not always the same; or, in other words, the fact was not yet known, that the *pressure of the air was, sometimes, greater than at others.* But as Torricelli's tube excited the attention of men of science, it was soon discovered that the quicksilver did not always stand at the same height; and, moreover, that its rising, or falling, was usually accompanied, or followed, by a change of weather. The quicksilver being found to vary from about 27 to 31 inches, a graduated scale was affixed to the tube, divided into inches and tenths of an inch, in order to show, with accuracy, these variations; this instrument was called the *weather-glass*, and, afterwards, received the more scientific name of *barometer*.

420. The word *barometer*, is from two Greek words, *baros*, weight, and *metron*, measure, signifying to weigh the atmosphere. Let a tube, A, of nearly three feet in length, closed at one end and open at the other, be filled with quicksilver and inverted in a

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419. What fact respecting atmospheric pressure was still unobserved? How was the variation in atmospheric pressure discovered? The weather-glass.

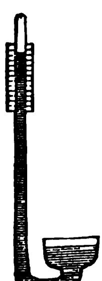
420. Meaning of the word barometer. Construction of the barometer. Why does not the quicksilver in the tube of the barometer run into the cup? What proves that the column of quicksilver in the barometer has the same *weight* as a column of air?

cup, B, also containing quicksilver. If the tube were open at the top, (according to the law that all fluids seek an equilibrium,) the quicksilver from the tube, would descend to a level with that in the cup. But at the top of the column of quicksilver there is no pressure, because, when the tube was filled with this fluid, all the air was excluded, and when on inverting the tube, a space was left at the top by the descending of the quicksilver, this space was a perfect *vacuum*, and, therefore, all downward pressure upon the column of fluid in the tube is removed. But the air presses upon the quicksilver in the cup, and this forces the fluid upwards, or which is the same thing, supports it thus suspended, with the open end of the tube immersed in the contents of the cup. And this column of quicksilver must have the same weight as a column of the atmosphere of the same base, or it would not be thus balanced by it. As the variations in the barometer correspond to the variations in the weight of the air at a given place, this instrument becomes a *weather-glass*, indicating changes in the weather. The *rise* of the barometer denotes *fair weather*, its *fall* denotes *stormy weather*. A violent wind is often preceded by a very sudden and great descent of the mercury.

Fig. 152.

421. Barometers are sometimes made with the lower end of the tube *bent*, (as in Fig. 153,) and terminating in a small open cup containing mercury. The principle of their construction and operation, is the same as in the barometer with the straight tube.

Fig. 153.



422. In describing the air-pump, we remarked that with it, was usually connected a part called the *barometer-gauge*. The object of this is to measure the degree to which the air is rarefied. When the exhaustion of the air, in the receiver, commences, the quicksilver of the barometer falls, because the air which supports it is lighter. If it fall a thousand degrees below where it stood before the action of the air-pump began, the air in the receiver is said to be rarefied 1000 times.

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421. What does the variation in the barometer prove?
422. Barometer-gauge connected with the air-pump.

Uses of the Barometer.

423. 1st. The barometer enables us to determine the *exact weight of a column of atmospheric air*, since this is equal to the weight of a cylinder of quicksilver, thirty inches in length.

424. 2d. The barometer is used for the purposes of determining the *height of mountains, ascent of balloons* &c.; as atmospheric pressure is less in proportion to elevation, the barometer falls in the same ratio. It is a common rule, that the *barometer falls* 1 *inch for* 1000 *feet of elevation.* Thus, in ascending a mountain, we should infer from the fall of the quicksilver ½ an inch, that we were 500 hundred feet above the level of the sea. Upon the summit of Mont Blanc, an elevation of 15,000 feet, the barometer falls about 15 inches.

425. 3d. The *barometer is of great use to the mariner*, who in unknown climates, is often able, by its variations, to foresee and prepare for sudden changes of weather. "The watchful captain of the present day, trusting to this extraordinary monitor, is frequently enabled to take in sail, and to make ready for the storm, when in former times, the dreadful visitation would have fallen upon him unawares."*

426. 4th. The *sudden fall of the mercury* in the barometer, generally *denotes rain or wind*, or what we call bad weather.—Though, in such weather, we complain of the heaviness of the air, it is, in fact, its lightness that causes the feelings of dullness and oppression which we experience. For at each inspiration of the breath, we take in less air when it is rarefied than when it is more dense; on the contrary, the man in the diving-bell at the depth of thirty-four feet of water, where the pressure is that of two atmospheres, breathes air of twice the usual density.—*When the air is more light or rare than usual*, the damp vapors and unhealthy gases, which, supported by pressure from below, floated in higher regions, now *descend towards the earth*. These vapors and gases have an unfavorable influence on the human system, obstructing perspiration, the free play of the lungs, and the circulation of the blood, and in this way giving rise to diseases of various kinds. When therefore we see fog hanging over the surface of the earth, and smoke falling instead of rising, we may

* Arnott.

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423. Height of the atmospheric column determined by the barometer.
424. Effect of elevation upon the barometer.
425. Use of the barometer to the mariner.
426. What is indicated by the sudden fall of the barometer? Air lighter in bad weather. Effect of a light atmosphere upon the human system.

infer that the surrounding air is lighter than when fog and smoke rise into higher regions of the atmosphere.

427. As the falling of the barometer denotes bad weather, so its rising announces fair weather, though these indications are not always to be depended on, especially when the variations in the height of the mercury are slow and inconsiderable. It is stated by English writers, that, on the occasion of the great Lisbon earthquake, the barometer, even at the distance of Great Britain, fell five or six inches; a phenomenon which is scarcely ever observed to take place, at the surface of the earth, under any circumstances.

428. The mean pressure of the atmosphere at the level of the sea, is proved to be nearly the same in all parts of the earth.—The mean height of the mercury in the barometer has been found to be above 30 inches, in various places in the torrid, temperate and frigid zones.

429. In making accurate observations with the barometer, it is necessary to have attached to this instrument a *thermometer*, with a scale of correction to show how much to add or subtract from the height of the mercury, on account of changes of the temperature. The mercury being made lighter by heat, will rise in the barometer tube, when no change has taken place in the pressure of the air. The thermometer shows, exactly, the degree of this expansion of the mercury by heat, and therefore what must be *subtracted* from the height of the barometer, in calculating upon the weight and pressure of the atmosphere. On the contrary, in cold weather, the mercury is heavier, and consequently will stand lower in the barometer, although the pressure of the air may be the same; something therefore must then be *added* to the report of the barometer. At the *equator* we should have to *subtract* from the height of the barometer, while in *the frigid zone* we should *add* to it; and this according to the degrees of temperature indicated by the thermometer.

Effect of Heat upon Air.

430. *Heat*, which so much affects solids and liquids, *has a powerful influence upon air*. Of this we are continually reminded by the changes of temperature around us; thus we say, the air

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427. What is indicated by the rising of the barometer? Fall of the barometer at the time of the Lisbon earthquake.

428. Mean pressure of the atmosphere at the level of the sea.

429. Use of connecting the thermometer with the barometer. Effect of temperature upon the barometer.

430. Causes of variations in the temperature of the air. Effect of heat upon air

is chilly, warm, cold, &c. But as the moisture or dryness, the stillness or motion of the air, all conduce to these variations of temperature, we are not to attribute them to heat, only. *Heat expands air*, and thus rarefies, or makes it lighter. Let a bladder, tied at the neck, and containing a small quantity of air, be held near the fire, the sides will soon begin to be pressed out by the expansion of the air within. On removing the bladder to a colder place, the air will condense, and its sides collapse as before.

431. The *balloons* first used were filled with *hot air*, which, being lighter than the atmosphere around, arose, and floated in it. Dr. Arnott says, "the first balloon was constructed by a man ignorant of what he was really effecting. Seeing the clouds float high in the atmosphere, he thought that if he could make a cloud, and inclose it in a bag, it might rise and carry him with it. Then erroneously deeming smoke and a cloud the same substance, he made a fire of green wood, wool, &c., and placed a great bag over it, with the mouth downwards to receive the smoke. He soon had the joy to see the bag full, and ascending; but he understood not that the cause was the hot and dilated air within, which being lighter than the surrounding air, was buoyed up, while the visible part of the smoke, which chiefly engaged his attention, was really heavier than the air, and was an impediment to his wishes."—Montgolfier, of France, may be considered as the inventor of the air-balloon. To an elliptical bag of silk, 74 feet in length, and 48 in breadth, he attached a car for aerial travelers; and succeeded in raising this immense balloon by means of air, heated by burning combustibles in a grate, below the silk bag. The discovery of the properties of hydrogen gas, soon caused that substance to be substituted for heated air, in inflating balloons.

Smoke.

432. The ascent of *smoke*, is caused by the air becoming lighter by heat. Smoke consists of the vapor, gases and dust, which arise from burning fuel, and is borne upward by the rising current of heated air, in the same manner as straws and other light substances are carried along by a stream of water. All that is visible in smoke is really heavier than air, and soon falls, settling upon the sides of chimneys, or the roofs of houses, and surrounding objects, in the form of soot or fine powder. As hot air is continually rising in a heated chimney, its place is supplied by

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431. First attempt to construct a balloon. Inventors of the air-balloon.

432. Why smoke ascends. What smoke consists of. Is smoke lighter than air? Process which goes on in a heated chimney. The chimney does *not draw* smoke.

colder air, which moves in all directions toward the fire place, to *fill the void.* This colder air, being, in turn, heated, rises also in the chimney, which is thus filled with a column of air much lighter than a column of atmosphere of the same height, and therefore issues from the top of the chimney, being forced up by the colder and denser air which rushes in at the fire-place. We perceive therefore, that to say the chimney *draws* smoke is not strictly accurate, since it is the current of heated air which bears the smoke upward. We may now understand why a door or window should be opened to free an apartment from smoke;—a current of fresh air being thus thrown in, not only promotes the combustion of fuel, but, by its pressure, impels the lighter air of the chimney upwards.

LECTURE XXVI.

WINDS.—THEIR CAUSES AND EFFECTS.

433. *Wind is air in motion. Currents of air are caused by variations of temperature.* When any part of the atmosphere is more heated than the surrounding air, it becomes lighter, and rises, while the heavier air rushes in to supply its place; and this, in turn, becomes heated, and ascends, and thus a current of air is produced which is always *in the direction toward the greatest heat.* There is a rush of air from open doors or windows towards the heated fire-place of a room. If, when the air is calm, a fire be made of straw or other light combustibles in an open field, currents of wind will begin to flow *towards the fire.* During the conflagration of a building, the same fact will be strikingly manifested, for as the heat, and consequently the rarefaction of the air becomes greater, the force of the currents rushing to take the place of the ascending air, is consequently greater.

434. The sun being the great source of heat to the earth, it situation must, of course, greatly influence the direction of winds. If the earth did not revolve on its axis, one portion of its surface being then continually more exposed to the rays of the sun, the air would be here the most rarefied and ascend into higher regions, like smoke from a great fire, while, towards this point, would be

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433. Causes of currents of air. Why does the wind blow towards a fire?
434. Cause of the constant east winds at the equator. Where are the winds most violent?

impelled the surrounding colder, and heavier air. But as the earth does revolve on its axis, it follows, that successive portions of its surface are presented to the sun, and become heated; now as the heated part is constantly moving eastward because the earth revolves from west to east, and carrying in that direction the rarefied air, there is generally a current blowing in this direction, or a constant *east wind at the equator*. The equatorial region being that part of the earth which is most heated, the equilibrium of the air is here most disturbed, and winds most violent and terrific.

435. The laws of mechanics with respect to the motion which results from the composition of two or more forces, influence the action of the winds, no less than of solid, moving bodies. The *direction* of the wind may depend on various causes, being the *resultant* of two or more currents, or forces. As we go from the equator to about the 30th degree of latitude, the wind is found to vary from the east point, so as to become north-east on the northern side, and south-east on the southern side of the equator.—This is because the equatorial parts being hotter than any other on the globe, the currents of less rarefied air from the north and south move that way, but the northern current meeting with the *eastern*, or that which follows the diurnal motion of the earth, the resultant is the *north-eastern wind;* while the southern current also falling in with the eastern, produces, by the composition of the two forces, a *south-east* wind. These constant winds which always blow nearly in the same direction, from their great importance for navigation and commerce, are called *trade-winds*.—They prevail mostly in the Pacific and Atlantic oceans, and in the seas connected with them.

436. Currents of air also, in the seas between Asia and the equator, produce the *monsoons, or shifting trade-winds*. These differ from the constant trade-winds, because they change their course every half year, when the sun changes its position from the northern to the southern side of the equator; that is from March to September, or when the sun is north of the equator, the monsoons blow from the south-west; while the remaining part of the year, or when the sun is south of the equator, they blow from the north-east.—About the period of the equinoctial changes, there is a change in these winds, or, as the sailors term it, "*a breaking up* of the monsoons;" the seas where they prevail, are then subject to storms, hurricanes, and dead calms. The Indian ocean is most affected by these winds. When the sun is north of the equator, the sur-

435. Motions of the wind governed by mechanical laws. Variations of wind as we go from the equator. Trade winds, how formed?

436. Monsoons. Breaking up of the monsoons. Why the Indian ocean is most affected by them.

rounding Asiatic coast, being exposed to its direct rays, is hotter than the Indian ocean, and the wind blows from the ocean towards the coast; when the sun is south of the equator, the ocean being more heated, the wind blows towards it from the coast. Navigators to China and the East Indies, are, therefore, obliged to pay much attention to these winds.

437. *Land* and *sea breezes* are *periodical* winds which change their direction every day; they are chiefly confined to tropical regions, where the wind blows towards the coast during the day, and towards the sea during the night. The land reflects the rays of the sun more powerfully than the water; therefore, during the day, the air over the land is more rarefied than that over the water, and rises into higher regions of the atmosphere, while the surrounding cooler and denser air rushes in to fill the void. As soon as the hot sun darts his scorching beams upon the islands and coasts of the torid zone, the refreshing sea breeze comes to revive with its balmy breath the parching land and fainting inhabitants.

Who, in contemplating the beautiful provisions of nature, can doubt, that nature, herself, is under the control of a wise and good Director! How many facts of science reveal to us that the whole creation is but a chain of infinite and harmonious relations, the one depending upon and influencing the other, and all upheld by one governing and changless mind! And how often in the moral government of God, do peace and consolation, like the sea breeze which is produced by the scorching rays of the sun, accompany the very afflictions that threatened to overcome the feebleness of man; how wisely and beautifully balanced, are both moral and physical relations!

438. The *land* breeze begins, at evening, to blow towards the sea, and continues through the night; this change is owing to the rapid cooling of the air on land, when the sun's rays are withdrawn, while the water which had absorbed the heat to a considdepth below its surface, has now a warmer and rarer atmosphere than the surrounding coast, and the wind always blows to that point where the air is lightest. This subject may be illustrated by the following simple experiment. In the middle of a large vessel of cold water, put a small vessel filled with hot water; the former representing the ocean, the latter, an island, with the air rarefied by heat. Hold a lighted candle over the cold water (at A) and blow it out; you will see the smoke which represents the denser air, moving towards the vessel containing hot water. Now fill the lar-

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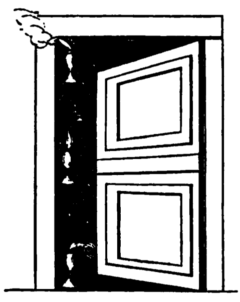
437. Land and sea breezes. Sea breeze. Physical and moral relations.
438. Land breeze. Experiment illustrating the phenomena of land and sea breezes.

Fig. 154.

ger vessel with warm water, ai smaller with cold, and hold the dle over the hot water (at B, smoke will move in the directi the warmer atmosphere.

439. In the torrid zone there is a continual ascent of ra air, which spreads to the north and south in a direction op to the trade-winds below. These upper currents becoming c above, at last descend and mix with the lower air of the noı and southern regions, thus restoring to them what they lose l lower currents which they are cons sending towards the equator. In a room, the same process of cold air ing in below, and warm air rushir above, is continually going on.

Fig. 155.



Hold a lighted candle at the top of aı door way, and the blaze will be borne ot by the current of rarefied air. Place a candle at the bottom of the passage, aı blaze will be blown inward by the count rent of cold air; while half way betwe top and bottom of the passage, the blaz rise perpendicularly, showing that here, is no current of air.

440. Wind may cause the baro to fall by diminishing atmospheric sure, or a quick motion of air in a zontal direction may suspend the or part of its weight; as a person in skating rapidly, mj over ice that would not bear his weight if he were standing The force of a current of air is increased, in proportion as the sage through which it runs is diminished.

Fig. 156.

Take a small tube, (Fig. 156,) c both ends, and blow forcibly thro at the same time let a lighted can placed near in the tube, and yo perceive the flame to be forced tc it. While the air within the tube rest, it exerted a pressure again sides, equal to the pressure of aiı out, therefore the two forces ba each other. But when, by bl through the tube, the horizontal ı diminished the pressure within, t ternal pressure forced the air, an it, the flame of the candle into t

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439. Why does not the air of the polar regions become exhausted, currents towards the equator? Experiment showing the currents whi in motion in a warm room.

440. Atmospheric pressure diminished by wind.

We perceive therefore, that winds, by diminishing atmospheric pressure, must effect the barometer. Experience verifies this, for it is found, that during high winds the barometer falls rapidly.

LECTURE XXVII.

METEOROLOGY.—STEAM.—ELASTIC FORCE OF STEAM. STEAM ENGINE.

441. *Meteorology* is that branch of philosophy which treats of weather, the formation of vapor, fog, dew, rain and snow; also of thunder and lightning, and other atmospheric phenomena produced by electricity.

442. *Evaporation* is the slow change of liquids into vapor; boiling is a more rapid process of the same kind. The sun's rays falling upon the surface of the land or water, are sufficiently powerful to cause evaporation, raising into the atmosphere vast quantities of vapor, which serve as a storehouse, from whence are sent forth, dew, fog, rain, and snow. *Clouds* are a collection of condensed vapor, which though invisible near the surface of the earth, where the heat is greater, and the vapor consequently rarer, appears as a dense mass, when cooled in the higher regions of the atmosphere.

443. *Fogs* are condensed vapor, differing from clouds, only in being suspended nearer the surface of the earth. When the surface of the earth or water is warmer than the surrounding air, the aqueous vapor with which the air, in a greater or less degree, is always charged becoming heated by contact with the warmer surface, in attempting to rise, is immediately condensed by the colder air around it, and thus a *fog* is produced. But when the air is warmer than the surface of the earth or the water, the vapor is not condensed, but rises into higher regions forming clouds. The fogs which often prevail at night, arise in consequence of the air being cooled more suddenly than the surface of the earth, by the absence of the sun. When the beams of the morning sun begin to warm the earth, a dense fog sometimes appears; this is because the sun's rays penetrate the air without heating it and the earth, in consequence, becomes warmer than the air. We

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441. What is meteorology?
442. Evaporation.
443. Fogs. Fogs at sunrise. Vapor which seems to issue from the mouth in breathing.

may now understand, why, in a summer morning, fogs are s hanging over lakes and river; and, why, in a cold morning, a por, like smoke, seems to issue from the mouth in breathing: cause in both cases is the same, that is, vapor, meeting with colder than itself, is condensed.

444. *Frost* is formed when vapor is condensed as soon a rises and is *frozen* before it ascends from the surface of earth.

Dew is produced when the vapor which is formed at the face of the warm earth is condensed before it can ascend; when the surrounding air is not cold enough to congeal it i frost. Thus the grass and flowers are often found cove with moisture on a summer's morning, though there has b neither fog nor rain during the night. A pitcher filled with water, will be seen, in a warm day, covered with moisture; outside of the pitcher being colder than the air in contact witl condenses the vapor which the air held suspended. This m ture is formed upon the same principle as dew; the cold pitc representing the cold air which condenses vapor arising from earth.

445. *Mist* is the vapor of clouds becoming more dense, so the aqueous particles acquire sufficient weight to cause then fall, though they are too small to appear visible, in drops. *R* is occasioned by the sudden condensation of aqueous vapor, the consequent union of many minute particles, which, becon more dense are more readily subject to the law of cohesive traction, and, uniting, form drops; these drops fall to the e by their own gravity. A wind warmer than the temperatur the cloud, will dissolve it into an invisible vapor, while a co wind will condense the vapor, and cause it to fall in drops.

446. *Snow* is formed by the freezing of minute particles of va while they are condensing. *Hail* is formed by drops of r which are frozen, in descending, as they pass through regions col than those in which they were formed. In a warm day we sometimes surprised by a hail storm; this is occasioned by sudden meeting of hot and moist air with a very cold wind.

447. We find constant changes going on in the atmosphere, the ascent of water in a state of vapor, and its descent, in v ous forms, upon the earth. Many blessings accompany th

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444. Frost. Dew. Dew upon flowers. Cause of moisture on the side of a pitcher containing water.

445. Mist. Rain. Effects of wind in producing rain.

446. Snow. Hail.

447. Evaporation a source of novelty and beauty in its effect upon th mosphere. Condition of the earth should the process of evaporation c Wisdom of God's providence, and our obligations to gratitude and obedie

changes! To them, we owe the variety of coloring which we see in the clouds, where, blending with the most gorgeous hues, are the faintest and most delicate tints which nature presents, or imagination can paint; and exhibiting forms, by turns, grotesque, picturesque, beautiful and sublime;—who can tell how much of poetical inspiration, of calm delight, and of devout meditation, the contemplation of the clouds has afforded to the successive generations of men, who, by turns have gazed upon their etherial forms and changing colors. How tame and dull would be the aspect of the heavens, were they always to present an unvarying appearance, even though this were the beauteous calmness of a summer sky!

Were the process of evaporation to cease, the earth overcharged with moisture, would destroy by this excess the vegetation which it now nourishes. There would be no longer rain or dew to refresh or purify the air. Mountainous regions, after sending forth their watery stores in rivulets and rivers, would become impoverished and withhold their gifts; while the ocean, losing nothing by evaporation, and swollen by supplies no longer taken up, would overleap its bounds and extend its dominions over the land. Such would be the consequences of an interruption in the wise and constant government of God, in this department of nature. Yet many of God's creatures, calling themselves rational, never reflect, that there is anything in all this to call forth their love, or admiration. They are like children enjoying the support and protection of a kind and watchful parent, without gratitude, or even consciousness of their obligations. There are men who can "bear to live, and dare to die," indifferent to the character and acquirements of the Being whose providence not only sustains them by the general and constant laws with which He governs "times and seasons," but who watches over the minutest circumstances of their existence.

Steam.

448. *Boiling* is a rapid process of converting water into vapor, and the vapor thus produced is called *steam*. We must refer to Chemistry for an explanation of the process of boiling, and the properties of steam: to Natural Philosophy properly belongs the consideration of the *mechanical agencies* of steam. The pressure of the atmosphere opposes itself to the formation of steam, and where this pressure is removed, liquids can be made to boil with much less heat than before. Even the warmth of the hand is found sufficient to make alcohol boil, when relieved from atmospheric pressure.

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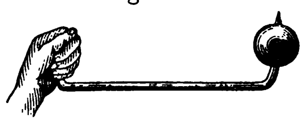
448. Boiling. Atmospheric pressure opposes the formation of steam Pulse-glass.

Fig. 157.



The figure represents a *pulse-glass*, consisting of a glass tube, with a bulb at each end. The glass is partly filled with alcohol, and the air is expelled by causing the liquid to boil; the open end is then hermetically* sealed. There is now a vacuum over the liquid. On holding, in the warm hand, the bulb which contains the liquid, it will begin to boil, and steam or vapor will pass over into the cold bulb, where it will be condensed, or again become liquid; thus the whole contents of one bulb may be transferred into the other.

449. Liquids boil with less heat in elevated situations than in lower regions, because the pressure of the atmosphere is less. Under the exhausted receiver of an air-pump, a small increase of temperature will cause a liquid to assume the state of vapor.

450. The peculiar property of steam, and that which renders it of such vast importance as a mechanical agent, is its *great elastic force*. "The name of steam engine," says Dr. Arnott, "to most persons, brings the idea of a machine of the most complex nature, and hence intelligible only to those who will devote much time to the study of it; but he who can understand the common pump, may understand a steam engine. It is in fact only a pump in which fluid is made to impel the piston, instead of being impelled by it, that is to say, in which the fluid acts as the power, instead of being the resistance. It may be described simply as a strong barrel, or cylinder, c, with a closely fitting piston in it, at *b;* the piston is driven up and down by steam admitted alternately above and below, from a suitable boiler; while the end of the piston-rod, *a* at which the whole force may be considered as concentrated, is connected in any convenient way with the work that is to be performed. The power of the engine is proportioned to the size or area of the piston on which the steam acts, with a force according to the density, of from 15 to 100 or more pounds to each square inch.

Fig. 158.

In some of the Cornish mines, there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the efforts of six hundred horses. "Sometimes the wonderful piston-rod may be seen acting upon one end of a great vibrating beam, with the other end of which, immense water-pumps are connected, whose motion causes almost a river to gush up from the bowels of the earth. At other times working a crank, it is seen urging complicated machinery; and one engine, stretching long arms over a great barrack or manufactory, will keep thousands of spinning-wheels in motion, while at the same time it is carding the material of the thread, and weaving the cloth. In like manner one steam engine in a great

* That is, seale by melting the glass at one end, and closing it when in a soft state.

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449. Why will liquids boil with less heat in elevated situations than in lower regions and with a small increase of temperature under the air-pump receiver.

450. Elastic force of steam. Steam engine compared to a pump. How

metropolitan brewery, may be seen at once grinding the malt, pulling up supplies of all kinds from wagons around, pumping cold water into some of the coppers, sending the boiling wort from others up to lofty cooling pans, perhaps also working the mash-tub, drawing water from the deep wells under ground, loading the drays, and in a word, performing the offices of a hundred hands.

"Again there are manufactories where this resistless power is seen, with its mechanic claws seizing masses of iron, and in a few minutes delivering them out again, pressed into thin sheets, or cut into bars or ribands, as if the iron had become to it like soft clay in the hands of the potter. One steam engine, four miles from London, is at the same instant filling all the water reservoirs and baths and fountains of the finest quarter of the town. And for some years now, in all parts of the world, has this wonderful piston-rod, working at its cranks, been turning the paddle wheels of innumerable steamboats, thus setting at defiance the violence of the winds and waves, and the currents of the fleetest rivers, while it carries men and civilization into the remote recesses of all the great continents. Wherever a river leads, the region watered by it, although concealed, perhaps, since the beginning of the world, are now called by the steam-engine from their solitudes, to form parts of the great garden, which civilized man is beautifying. Such are a few of the prodigies which this machine is already performing, and every day is witnessing new applications of its utility.

451. "It regulates with perfect accuracy and uniformity, the number of its strokes in a given time, counting or recording them moreover, to tell how much work it has done, as a clock records the beats of its pendulum, it regulates the quantity of steam admitted to work; the briskness of the fire; the supply of water to the boiler; the supply of coals to the fire: it opens and shuts its valves with absolute precision as to time and manner; it oils its joints; it takes out any air which may accidentally enter into parts which should be vacuous: and when anything goes wrong which it cannot of itself rectify, it warns its attendants by ringing a bell; yet with all these talents and qualities, and even when exerting the power of six hundred horses, it is obedient to the hand of a child; its aliment is coal, wood, charcoal or other combustibles; it consumes none while idle; it never tires, and wants no sleep; it is not subject to malady when originally well made, and only refuses to work when worn out with age; it is equally active in all climates, and will do work of any kind; it is a water-pumper, a miner, a sailor, a cotton spinner, a weaver, a blacksmith, a miller, &c. &c.; and a small engine in the character of a steam poney, may be seen dragging after it on a *rail road*, a hundred tons of merchandise, or a regiment of soldiers, with greater speed than that of our fleetest coaches. It is the king of machines, and a permanent realization of the Genii of eastern fable, whose supernatural powers were occasionally at the command of man."

452. "The chief parts of the engine are the *boiler* A, the *cylinder* C, the *piston-rod* I J, the *condenser* L, and the *air-pump* M. B, is the *steam-pipe*, branching into two arms, communicating respectively with the top and bottom of the cylinder, and K, is

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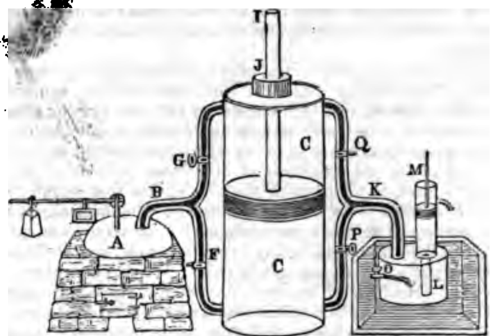
does the figure illustrate the action of a steam engine? To what is the power of the steam engine proportioned? Various operations of steam engines. Application of steam power applied to manufactories. Steam power applied to navigation.

451. The steam engine regulates and records its own motion, &c.

452. Describe the parts of the steam engine.

Fig. 159.



the *eduction-pipe*,* formed of the two branches which pro from the top and bottom of the cylinder, and communicates tween the cylinder and the condenser. N, is a *cistern* or we cold water in which the condenser is immersed. Each bra of pipe has its own *valve*, as F, G, P, Q, which may be op or closed as the occasion requires.

453. "Suppose, first, that all the valves are open, while st is issuing freely from the boiler. It is easy to see that the st would circulate freely throughout all parts of the machine, ex ing the air, which would escape through the valve in the pi of the air-pump, and thus the interior spaces would all be f with steam. This process is called blowing through; it is h when a steamboat is about setting off. Next the valves, F, Q are closed, G and P, remaining open. The steam now p sing the cylinder forces it down, and the instant when it gins to descend, the stop-cock O, is opened, admitting cold wa which meets the steam as it rushes from the cylinder and ef ually condenses it, leaving no force below the piston, to op its descent. Lastly, G and P being closed, F and Q are ope the steam flows in below the piston, and rushes from abov into the condenser, by which means the piston is forced up a with the same power as that with which it descended. M while the air-pump is playing, and removing the water air from the condenser, and pouring the water into a reser whence it is conveyed to the boiler, to renew the same circuit."†

* From *educo*, to draw out.
† Olmsted.

453. Operation of the steam engine.

LECTURE XXVIII.

ATMOSPHERIC PRESSURE UPON WATER.—PUMPS.—SYPHONS.

Pumps.

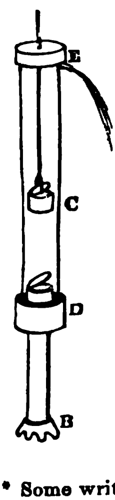
454. We have seen, in examining the barometer, that the *pressure* of the *atmosphere* is sufficient to support a column of 30 inches of mercury, and a column of about 34 feet* of water. It is upon this principle that we account for the rise of water in a pump, when the air within is removed by the operation of pumping, and the weight of external air meeting with no counteracting force presses the liquid upward into the vacuum.

455. It is a familiar fact that liquid may be drawn from a cask or any other vessel by means of a straw, or other tube applied to the surface of the liquid, and at the same time held to the mouth.

The air being first withdrawn from the tube by *suction*, the liquid rushes up to fill the vacuum.

Suction Pump.

Fig. 160



The common household pump consists of a large *tube*, E, in which is a *piston* made to fit, air-tight, the bore of the tube. In the piston is a *valve*, C, opening upwards like a trap-door, which allows the air and water to rise through it, but not to descend. This piston, sometimes called the bucket, is moved up and down by a rod fastened to a handle or lever. The pump usually consists of two parts; the upper and wider part, E D, is called the *pump-barrel;* the piston moves in this; the part of the pump, D B, which is smaller in diameter, is called the *suction-tube.* At the joining of these two parts, is a fixed valve, D, which opens upwards. E, is a pipe or spout, serving as a passage for the water which is raised.

456. The parts of the pump being now described, we will consider its mode of operation. When the piston is let down as low as the fixed valve, D, both valves are closed by their own weight. Let the piston now be drawn up as at C, and the column of air

* Some writers say 32 feet, some 33 feet;—34 feet is undoubtedly the *maximum* height to which a column of water can be raised by atmospheric pressure.

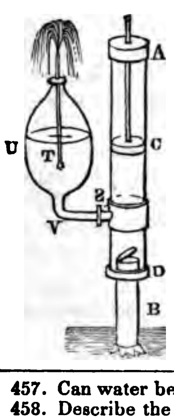
454. To what height will the pressure of the atmosphere support mercury or water? On what principle does water rise in a pump?
455. Suction. Describe the suction-pump.
456. Its mode of operation.

which rested upon it is also raised, leaving a vacuum bet
and D; the air below D being relieved from pressure, e
and lifting up the valve, D, passes through it and fills the v
A few strokes of the piston thus exhausts the pump of air,
water, relieved from its weight, is forced upward by the p
of the incumbent atmosphere. Rushing up through the
tube, the water lifts the valve, D, and enters the pump
When the piston now descends, it presses upon the water
not being able to return through the valve D, pushes up th
C, and when the piston is next raised, all the water abc
lifted up, and begins to escape through the spout E; thu
the piston is raised, the valve D rises and the valve C
and when the piston is depressed, D falls and C rises.

457. It should be observed, that although the water is into the pump-barrel by the *pressure of the atmosphere*, it from thence to the level of the spout by means of strength upon the piston. Therefore, as the pressure of the atm will sustain a column of water about thirty-four feet in hei valve at the top of the suction-tube may be this distance fr surface of the water in the well; and as the water after above the suction-tube, is raised by *lifting*, the height to v is afterwards carried will depend on the length of the pis and the degree of strength employed. When we say tha will not rise in a pump above thirty-four feet, we mean o atmospheric pressure will not raise it above that distance.

The Forcing-pump.

Fig. 161.



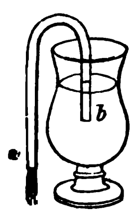
458. The *forcing-pump* consists of *rel*, A B, and a *piston* or *forcer*, C. are *two fixed valves*, one at D, and th at S, in the *branching-pipe* V. The is solid, or without any valve, therefc water cannot rise above it. When t ton is pressed down, the air between tl the valve, being subjected to pressure, the valve, S, and passes out at the brar pipe. Thus the valve S, answers the purpose as the piston-valve of the s pump, and the process of raising the until it ascends through the valve D, same as that which takes place in rai into the barrel of the suction-pump. I water being pressed upon by the piston

457. Can water be raised in a pump higher than thirty-four feet?
458. Describe the forcing-pump. How is the water in a forcin *made to flow* out in a steady current?

barrel of the forcing-pump, and having no other vent, is forced through the valve S. As the operation of a pump consists in applying power by separate efforts, it is evident that the water will not flow out in a steady current. The irregular discharge is remedied by the addition of an *air-vessel*, U, into which is fitted a *small pipe*, T, reaching nearly to the bottom of the vessel. This vessel, by the action of the pump, will at first be filled with condensed air; when water is forced in through the valve, S, it confines the air in the upper part of the vessel; on the admission of more water, the condensed air presses by its elasticity on the surface of the water which cannot return through the valve S, and is forced up the pipe T, in a *steady* stream. Thus, the condensed air first receives the force given by the piston, and reacts by its elasticity, like a spring upon the surface of the water, with a *nearly uniform power*.

459. The *fire engine* consists of two forcing-pumps, working together, which throw the water into an air vessel, from whence it passes into two, long, leathern tubes, called the *hose*. The hose may be pointed in any direction, and water thrown by the forcing pumps, to the roofs of the highest buildings.

Fig. 162.



460. There is a very simple instrument called a *syphon*, the action of which depends on the pressure of the atmosphere. It is used for drawing off liquors from one cask into another. Suppose *a b*, to be a *tube* having two arms of unequal length; this tube being filled with water, and the mouth of the shorter arm immersed in a vessel filled with any liquid, the liquid will run out until the vessel containing it is emptied. The cause of this action of the syphon may be thus explained. The liquid, which, at first, filled the longer arm, would flow out by its own gravity, and a vacuum being left, the pressure of the atmosphere upon the surface of the liquid within the vessel, would force that in the shorter arm of the syphon over the top; the same cause would continue to sustain the shorter column, and to impel the liquid over the top until the whole was exhausted.

461. This effect may be produced with any similar, bent tube, provided the shorter arm or column be less than thirty-four feet in length, otherwise the force of atmospheric pressure would be

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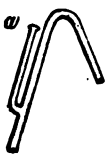
459. Fire engine.
460. Describe the syphon.
461. Why must the short arm of the syphon be less than thirty-four feet? Why must a syphon for drawing mercury be shorter than for drawing water? Syphon with a suction-pipe.

Fig. 163.



insufficient to force the liquid through the tube. Mercury may be drawn through a syphon in the same manner as water, but as this fluid is nearly 14 times heavier, the height of the syphon in this case must be proportionally shortened, since the mercury would only rise about thirty inches, as in the barometer. Syphons are sometimes made with a *suction-pipe* as at *a*, in which case a vacuum may be formed in the shorter arm, by the mouth.

Fig. 164.

462. An amusing toy called *Tantalus' cup*,* represents the figure of a man standing in a cup. The handle of the cup is a *syphon*, the short arm of which is nearly level with the mouth of the figure; the liquid can never reach the mouth of the figure as it flows out through the syphon handle.

463. Intermitting springs or fountains, are caused by drains in the earth communicating with reservoirs of water. These drains may be considered as natural syphons, which acted upon by atmospheric pressure, carry off the water, and then cease flowing, until rains or the melting of snows have again filled the reservoirs.

Synopsis.

464. 1. *Pneumatics treats of the mechanical properties of elastic fluids, chiefly of air.*

2. *Air is* MATTER, *because it is extended and impenetrable.*

3. *Air is invisible, because it is thin and transparent.*

4. *Air possesses weight; it is compressible and elastic.*

5. *The elasticity of air, increases with its density.*

6. *The density of the air diminishes upwards; or its pressure is in proportion to its depth.*

* Tantalus, in mythology is represented as having, for an offence against Jupiter, been plunged from a state of happiness into one of torment. His greatest punishment was that of everlasting thirst; being condemned to see a pure stream forever rising to his lips, but flowing back as soon as he attempted to drink of it.

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462. Tantalus' cup.
463. Intermitting springs.
464. Synopsis of Pneumatics.

7. *The air like water presses in all directions.*

8. *The pressure of the atmosphere on fluids causes the rise of water in pumps, and of mercury in the barometer.*

9. *The air-pump is an instrument used for exhausting the air from any vessel.*

10. *A vacuum is an empty space, or generally understood to mean a space emptied of air.*

11. *A condenser* is an instrument used for the purpose of pressing more air into a vessel; the air is said to be condensed, when heavier than common air. The operation of the air-pump and condenser are directly opposite, because the former rarefies, and the latter condenses air.

12. The barometer measures the *weight* of the atmosphere, the thermometer its *temperature.*

PART V.

ACOUSTICS.

LECTURE XXIX.

SONOROUS BODIES.—BELLS.—MUSICAL STRINGS.—ÆOLIAN HARP.

465. Acoustics is a word derived from the Greek, and signifies the science which treats of *sounds*.

This subject opens to us a train of moral reflections, as well as a curious and interesting field of scientific inquiry. The tender accents of affection, the solemn tones of prayer, the thrilling notes of music, the pealing of bells, and the burst of thunder all, are but *vibrations of air*. Deprived of sound, what a gloomy vacancy would exist in creation, and be felt in the heart of man! How grateful to our hearts is the music of nature, as heard in the lively carol of birds, the lowing of kine, with all the variety of sounds by which the brute creation, in their own true and expressive language, manifest their emotions. Inanimate nature too, seems by this wonderful gift of sound, to be endued with life and intelligence; the brook softly murmurs in its placid course,—the cataract in startling thunderings proclaims its tremendous force;—the light foliage responds to the gentle music of the summer's breeze; and bending forests, in mournful and mysterious tones, waft to our spirits, upon the wings of the autumnal blast, thoughts of the majesty and power of Him, "who walketh on the wings of the wind."

466. But interesting as is the voice of animate and inanimate nature, we value sound, chiefly, for the *power it gives mind of communicating with mind*. As sensation is to the soul the medium of holding communion with external objects, so is sound among human beings, and among the lower orders of animals, the link

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465. Definition of acoustics. Moral reflections upon sound.
466 Chief value of sound.

which connects their sympathies, the chain which binds their affections. To this power, we are indebted, not only for spoken language, but for its subsequent expression in written characters, and, consequently, for all human sciences.

> "The air is vehicle of sound:
> Remove but the elastic pulse of air
> And the same ear which now, delighted, feels
> The nice distinction of the finest notes,
> Would not discern the thunder from a breeze."

467. 1. *Bodies which produce sound are called sonorous bodies.*

2. *Air is the common medium which transmits sound;*

3. *The ear is the organ which receives the impression of sound.*

4. *The mind, only, is capable of the sensation produced by ound;—*

5. *This sensation is called hearing.*

Sonorous Bodies.

468. Those bodies are properly called *sonorous* which afford a sound distinct, and of some duration; such as bells, and the strings of musical instruments. Bodies which cause only a confused noise, like that of a stone falling upon a pavement, are not called sonorous. Thus philosophers make a distiction between *sound* and *noise.*

469. Sound is supposed to be produced by motion in the air caused by vibrations of the sounding body. Gold, brass, copper, silver, iron, and glass, being dense and elastic, are sonorous; while lead and wax being softer, are less capable of vibratory motion, and give only a confused and imperfect sound.

470. The vibration of a sonorous body gives a tremendous motion to the surrounding air, similar to that caused by throwing a stone into smooth water; the undulations becoming weaker the farther they are from the centre of the motion. It is proved that the intensity of sound decreases in the inverse ratio of the square of the distance; as, at 2 rods distant, the sound is 4 times weaker than at one rod distant, and at 3 rods distant, it is 9 times weaker.

471. The waves of air producing sound, differ, in this respect, from the *undulations* of water, viz; air being elastic, its motion does not consist of regularly extending waves, but of *vibrations*, or

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467. Repeat the five propositions respecting sound.
468. Sonorous bodies. Difference between sound and noise.
469. Cause of sound.
679. Intensity of sound decreases in the ratio of the distances.

motions backwards and forwards, like those of the sonorous body which produced them.

Fig. 165.

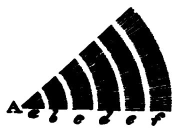
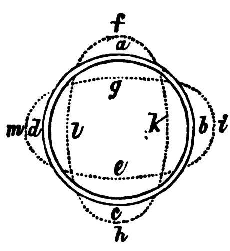


Figure 165 represents *waves of sound;* diverging from the point A they become weaker, as rays of light become fainter as they are more diffused. The points *a*, *b*, *c*, &c., with the intermediate spaces, represent undulations of air spreading in concentric circles. Each particle of air on receiving an impulse either directly from the sonorous body or by transmission, becomes agitated, moves back and forth like an oscillating pendulum, within a limited space, and at length ceases to move. But this particle has communicated motion to contiguous particles, which, in their turn, vibrate and communicate motion. On account of the extreme rarity and elasticity of air, vibrations of sound extend to a much greater distance than the circular waves of water. The undulations of air are also in a sphere extending upwards and downwards, as well as outwards, while those of water extend only upon a horizontal plane.

Bells.

472. It may at first thought, appear incredible that a bell actually changes its form every time it is struck; but this circumstance causes its sound. If light particles of dust lie upon the outside of a bell when it is struck, they may be seen to be agitated, which shows that the particles of the bell are in motion. A small bit of cork suspended to a bell, will be tossed back and forth when the bell is sounding, like a pendulum in motion.

Fig. 166.



473. Suppose the bell to be struck on the outside, at the point *a*; this part will tend towards *g*, while the parts *b* and *d*, tend towards *i* and *m*, and this action on these parts carries the point *c*, towards *e*. Though these parts soon spring back, on account of the elasticity of the metal, they have acquired a momentum which keeps them in motion; as the part *a*, having returned from *g* to *a*, tends towards *f*; the part *c* towards *h*; and the parts *b* and *d*, towards *k* and *l*. Thus, though the base of the bell is a circle, by being struck

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471. Waves of air differ from those of water. What does Fig. 165 represent? How is sound transmitted through the air?

472. What proves that the particles of a bell when it is sounding are in motion?

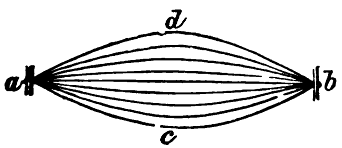
473. Describe Fig. 166.

it is changed into an ellipse (or oval form) of which the diameter is alternately longer in different directions. These ellipses grow smaller and smaller, like the vibrations of a pendulum when no longer acted upon by any moving power, until the particles ceasing to vibrate, the sound dies away. When a large bell rings, we perceive a mingling of sounds; this is owing to the difference in diameter of the upper and lower parts of the bell. We may consider a bell as composed of a series of rings placed one above another; those nearer the base having the greater circumference, perform their vibrations more slowly than the upper and smaller rings, consequently causing a variation in the succession of sounds.

Musical Strings.

474. The vibrations of musical strings are often visible to the eye, and when this is not the case, their existence may be proved by experiment; as fine sand, or bits of paper, will be thrown from the strings of a sounding violin or harp.

Fig. 167.



The *elasticity of any string causes a series of vibrations,* and therefore continuance of sound. Suppose *a b*, to be an elastic string fastened at the two ends; on drawing this string toward *c*, and then letting it go, it springs back to its straight position; but having acquired a momentum like that of a vibrating pendulum, instead of resting here, it passes towards *d*, nearly as far in the opposite direction. This is one vibration; the momentum then acquired produces other vibrations, each less than the former, until the resistance of the air and the friction of the string overcome the velocity, and the string rests in the original position, *a b*.

475. Sound is produced by vibrations in this manner; the string strikes against the particles of air which are contiguous to it, these particles being condensed by the pressure, and impelled forward, agitate the surrounding atmosphere; each agitation affects the contiguous parts, until the whole mass, within a certain distance, assumes a tremendous motion. Thus sound does not proceed from a progressive motion of air, but from a series of contractions and expansions of air.

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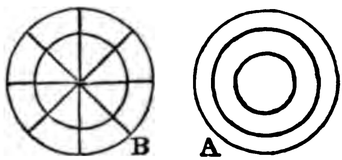
474. Vibrations of musical strings. Causes of vibrations in strings.
475. How is sound produced by vibrations?

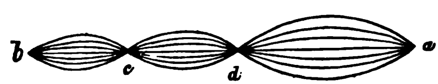
476. When any sonorous body vibrates, there are certain points or lines in its surface which remain *at rest*. These may be exhibited by experiment; let a pane of window glass be thinly covered with very fine sand, and the bow of a violin drawn across its edge; the moment a clear sound is produced, a part of the sand will be thrown off the glass by its vibration, while, in certain places, it remains undisturbed, forming a regular figure. The higher the tone, the more complicated the figure; thus the figure at A is less complex than at B. Another very simple experiment proves also that in vibrating bodies there are certain *natural stops* or *rests*; let a tumbler be partly filled with water, and draw the wet finger across its edge until a sound is produced. The vibrations of the water will be seen to proceed from certain regular points, while there are other points in which the water remains undisturbed.

Fig. 168.



477. A long, vibrating, musical string, thus divides itself into parts, with points of rest between them, on which points, bits of paper will remain, though they will be thrown by the vibrating

Fig. 169.



motion from every other part. Thus suppose *a b*, to be such a string, the part from *a* to *d*, vibrates as though it were fixed at *d*, and so on from *d* to *c*, and *c* to *b*. The sounds thus belonging to a single cord or string, and produced by its spontaneous division into different parts, constitute when heard together, or in succession, the simple music of nature itself. It is produced in the most perfect manner by the instrument called the *Æolian harp*.

"This is a long box or case of light wood, with harp or violin strings extended on its face. These are generally tuned in perfect unison with each other, or to the same pitch, excepting one serving as a bass, which is thicker than the others, and vibrates only half as fast; but when the harp is sus-

476. Regular figures produced by a vibrating body.
477. Natural rests in vibrating strings. Æolian harp.

pended among trees, or in any situation where the fluctuating breeze may reach it, each string according to the manner it receives the blast, sounds either entire, or breaks into some of the simple divisions thus described; the result of which is the production of the most pleasing combination and succession of sounds that ear has ever listened to, or fancy perhaps, conceived. After a pause, this fairy harp may be heard beginning with a low and solemn note, like the bass of distant music in the sky; the sound then swelling as if approaching, and other tones breaking forth, mingling with the first, and with each other, in the combined and varying strain. Sometimes one clear note predominates and sometimes another, as if single musicians alternately led the band: and the concert often seems to approach, and again to recede, until with the unequal breeze it dies away and all is hushed again. It is no wonder that the ancients who understood not the nature of air, nor consequently of simple sound, should have deemed the music of the Æolian harp supernatural, and in their warm imaginations, should have supposed that it was the strain of invisible beings from above, descended in the stillness of evening or night to commune with men in a heavenly language of soul, intelligible to both."*

LECTURE XXX.

MEDIUM OF SOUND.—THE EAR.—ECHO.—SPEAKING TRUMPET. VELOCITY OF SOUND.—MUSIC.—THE HUMAN VOICE.

Medium of Sound.

478. *Air is the common medium by which sound is transmitted;* or, in other words, the *vibrations of sonorous bodies cause similar vibrations in the air*, which, *striking upon our organ of hearing* produce a *sensation* in the mind. Sensation is the parent of *perception;* thus the sensation caused by vibrations of air produces a perception of sound; *emotions* follow these sensations and perceptions, varying according to the nature of the sounds which are thus mysteriously linked to the mind.

479. When we hear the sound of a musical string, the ear receives from the air, as many strokes as the string performs vibrations in the same time. If the string perform 100 vibrations in a second, the ear will receive the same number of impressions within the same period.

480. The sound of a bell struck under the receiver of an air-pump becomes weaker as the air is exhausted, until the sound

* Arnott.

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478. Medium of sound. Process of the mind in obtaining a *perception* of sound. What follow perceptions?

479. How do vibrations affect the ear?

480. Bell under an exhausted receiver. Sound more powerful as air is more *dense*.

ceases entirely. On admitting air into the receiver, the bell wi again be heard. When air is more dense than common, as in the receiver of a condenser, and in the diving-bell, sound is more powerful. In accordance with this law, it is observed, that o high mountains, where the air is light, sound is feeble. Th travelers among the Alps say, that when near enough to see huntsman on the neighboring cliff and observe the flash of hi gun, the report is sometimes so faint as scarcely to be audibl In caverns and mines, where the air is usually dense, sligh sounds appear louder and clearer than at the surface of the eart.

481. *Liquids* convey sounds with greater velocity than ai The sound of a bell rung under water, and the strokes of work men in a diving-bell, are heard by the people above. Fishes hea the slightest sounds, as the angler may observe, when, upon th least agitation of the water above them, they are seen to dart o in quest of a more quiet retreat.

482. *Solids* convey sounds with greater velocity than air o liquids. A long train of iron tubes was laid for the purpose o conveying water to Paris. Biot,* a philosopher of great research took advantage of this circumstance, to ascertain the exact differ ence between the power of air, and of metal, to transmit sounds He hung a small bell at the end of the iron tube, in such a situa tion, that the clapper struck against the tube, and the side of th bell at the same instant. The sound of the bell was conveye through the column of air inclosed within the tube, while th iron, itself, transmitted the sound made by striking the tube. By the person stationed at the other end of the tube in order to ob serve the succession of the two sounds, it was ascertained that iron transmits sound with about ten times the velocity of air.

If a person at one end of a log, scratch the wood lightly with a pin, the sound will be heard distinctly by another person whose ear is applied at the other extremity, though the air, itself, would not transmit so feeble a sound. By applying the ear to the ground, the tread of men and horses may be discovered, which, otherwise, could not be perceived. Savages avail themselves of this fact, to ascertain the approach of enemies, and animals instinctively resort to this method for discovering their prey. Previous to the great eruption of mount Vesuvius which buried Herculaneum and Pompeii, the animals in that region appeared much

* Pronounced *Be-o.*

481. Sounds conveyed by liquids.

482. Sounds conveyed by solids. Biot's experiment. Examples of the power of solids to convey sounds. Musical boxes. Sounding boards. Experiment with an iron poker.

disturbed, owing to the agitation of the earth, produced by distant, subterraneous explosions, and conveyed, by the ground, to the ears of these accurate observers.

Musical boxes give much louder tones when placed upon a table or other solid body, than when air, alone, is the conducting medium of sound. The vibrations communicated from the box, spreading throughout the particles of wood, cause a more extended surface to act upon the air. For this reason, musical instruments, as violins, guitars, &c., are furnished with *sounding boards*. If one end of an iron poker be placed on the lid of a kettle, and the other end held to the ear, the boiling of water within the kettle, will produce a sound louder than the rattling of a carriage over a pavement.

483. The power of solid bodies to conduct sounds, has led to the invention of an instrument called the *stethoscope*,* or chest-inspector, the object of which is, to convey, accurately, to the ear, the sounds produced by the motion of the heart, and the blood-vessels, situated near the organ. It consists of a simple wooden cylinder, one end of which, when used, is applied to the breast, while the ear of the physician rests upon the other end. "The action going on in the chest," says Dr. Arnott, "are the entrance and exit of the air in respiration, the voice, the motion of the blood in the heart and blood-vessels; and so perfectly do these declare themselves to a person listening through the stethoscope, that an ear once familiar with the natural and healthy sounds, instantly detects certain deviations from them. Hence this instrument becomes a means of ascertaining certain diseases in the chest, almost as effectually as if there were convenient windows for visual inspection."

484. "He who planted the ear," or the organ of hearing, is also the Creater of the air, or common medium of sound, and with that nice adaptation of means to ends which we behold in all the works of this mighty Architect, we find this organ wonderfully fitted to collect and concentrate the waves of air caused by vibrations of sonorous bodies. The human ear is a curious machine, far exceeding in its external construction the most delicate work of human art; and in addition to its various parts, all tending to promote the object of hearing, there is an invisible link connecting it with the mind, of the nature of which we can have no conception. And, yet, there have been men, and those calling themselves philosophers, who, contrary

* From the Greek *stethos*, the breast, and *skopio*, to examine.

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483. Stethoscope.
484. The ear a machine evincing design.

[illegible] dictates of common sense and the word of divine revela[illegible] have asserted that there is, in the universe, no great designer [illegible] that its creations are the product of mere chance or accident [illegible] such philosophers, and from such philosophy, may the youtl [illegible]!

[illegible]. We will now examine the parts of the ear, as they are [illegible] by external observation and anatomical dissection.

Fig. 178.

1st. We perceive, on looking int the ear, a wide mouthed tube, *a*. This is an ear-trumpet, the wid mouth of which serves to collec the waves of sound concentrated a the bottom or nervous part of th ear-tube. This tube, by the actio of certain muscles, is moveable b many animals, so that it can be direct ed towards the point whence a soun proceeds.

The tympanum or drum of the ear, *b*, is a tight draw [illegible] situated at the bottom of the ear-tube, upon whic [illegible] concentrated sound falls, and causes its vibration. The ai [illegible] the drum communicates with the external air, by an ope [illegible] called the *eustachian tube*, which leads to the back o [illegible]. When this tube is obstructed by wax, a degree o [illegible] is produced, and the cracking noise and return of acut [illegible] which is often caused by sneezing or coughing, is th [illegible] of the removal of this obstruction.

At *e* is the *vestibule* or entrance into the labyrinth; thi [illegible] with the drum of the ear by a chain of four smal [illegible] which serves to convey to the labyrinth, the vibrations fron [illegible]

The *labyrinth* is that complex, inner compartment of th [illegible] which, the nerve of hearing, or auditory nerve, is spread [illegible]ing. This nerve, like the optic nerve of the eye, is a con [illegible] link between the organ of sense, and the great *sensorium* [illegible]. The labyrinth is filled with water, so that when th [illegible]ne of the drum, acting upon the chain of small bone [illegible]es the portion of water next the chain, the pressure i [illegible] felt throughout the whole mass of water, and, thus, the vi [illegible] is conveyed to the lining of the labrynth, or the organ o [illegible]. The labyrinth consists of the *vestibule*, *e*, the thre [illegible]ular canals, *c*, which are imbedded in the hard bone, an [illegible]lea, *d*, which is a winding cavity, like a snail shell. I

[illegible]Parts of the ear. Tube of the ear. Drum of the ear. Vestibul [illegible]rinth; its parts.

this cavity are fibers stretched across, like harp strings, these are called the *lyra*.

486. We judge of the distance of sound by its intensity. The ear is capable of determining the direction from which sound proceeds. When we are doubtful respecting a sound, we turn the mouth of the ear-tube towards the point from which it seems to issue, and thus learn its nature, distance, direction and intensity.

The phenomena of hearing, considered as a sensation of the mind, belongs to the science of mental, rather than mathematical philosophy.

Reflection of Sound.

487. An *echo* is a reflected sound. Waves of sound or undulations of air moving forward, meet with some solid body and are thrown back, as waves of water are repelled by the river bank, or, as a marble rebounds, when thrown upon pavement.

According to a law of motion, when an elastic body strikes perpendicularly, against a hard substance, it is reflected back in the *same* direction: but when it strikes obliquely, it is thrown off, obliquely, in the opposite direction; the angle of reflection being equal to the angle of incidence. The same law may be applied to sound. Suppose a bell, *a*, to be struck,

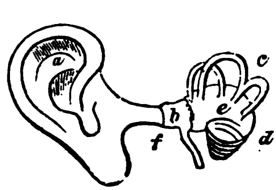
Fig. 171

and the waves of air to fall perpendicularly

to the dictates of common sense and the word of divine revelation, have asserted that there is, in the universe, no great designer, but, that its creations are the product of mere chance or accident. From such philosophers, and from such philosophy, may the youth of America be defended!

485. We will now examine the parts of the ear, as they are manifest by external observation, and anatomical dissection.

Fig. 170.



1st. We perceive, on looking into the ear, a wide mouthed tube, *a*. This is an ear-trumpet, the wide mouth of which serves to collect the waves of sound concentrated at the bottom or nervous part of the ear-tube. This tube, by the action of certain muscles, is moveable by many animals, so that it can be directed towards the point whence a sound proceeds.

2d. *The tympanum* or drum of the ear, *b*, is a tight drawn membrane situated at the bottom of the ear-tube, upon which the concentrated sound falls, and causes its vibration. The air within the drum communicates with the external air, by an open passage *f*, called the *eustachian tube*, which leads to the back of the mouth. When this tube is obstructed by wax, a degree of deafness is produced, and the cracking noise and return of acute hearing which is often caused by sneezing or coughing, is the effect of the removal of this obstruction.

3d. At *e* is the *vestibule* or entrance into the labyrinth; this is connected with the drum of the ear by a chain of four small bones, which serves to convey to the labyrinth, the vibrations from the drum.

4th. The *labyrinth* is that complex, inner compartment of the ear, over which, the nerve of hearing, or auditory nerve, is spread, as a lining. This nerve, like the optic nerve of the eye, is a connecting link between the organ of sense, and the great *sensorium*, the brain. The labyrinth is filled with water, so that when the membrane of the drum, acting upon the chain of small bones, compresses the portion of water next the chain, the pressure is instantly felt throughout the whole mass of water, and, thus, the vibration is conveyed to the lining of the labrynth, or the organ of hearing. The labyrinth consists of the *vestibule*, *e*, the three semicircular canals, *c*, which are imbedded in the hard bone, and the *cochlea*, *d*, which is a winding cavity, like a snail shell. In

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485. Parts of the ear. Tube of the ear. Drum of the ear. Vestibule *The labyrinth*; its parts.

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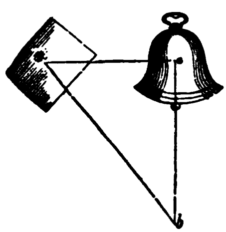
Fig. 171.



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486. How do you judge of the distance of sound?

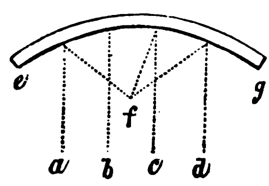
487. What is an echo, and how caused? Manner in which sound is reflected. In what case an echo will be heard by a person who utters the sound which is reflected? What is necessary in order to produce a perfect echo? *Speaking in a crowded room.*

hear it ;—thus, one person at the side of a mirror, sees tne image of another standing on the opposite side, though he does not see his own image.

As a wave of sound rebounds according to the same law as a wave of water or an elastic ball, in order that an echo may be perfect, the surface producing it must be smooth, and of some regular form. The various articles of furniture in a room, especially those of a soft texture, as carpets and curtains act unfavorably upon the vibrations which produce sounds. The labor of speaking audibly in a crowded room, is greater than in an empty one, the power of sound being much heightened by the vibrations of bare walls.

488. Plane and smooth surfaces reflect sound without either dispersing or collecting it; convex surfaces disperse, and concave surfaces collect sound. Plane, convex, and concave mirrors reflect light in a similar manner; for which reason, we see a true image in a plane mirror, a magnified and distorted one in a concave mirror, and a miniature image in a convex mirror.

Fig. 172.



Suppose *e g*, to be a smooth, concave surface, and that waves of sound fall upon *a*, *b*, *c*, *d*; these will be collected and brought to a focus* at *f*, and here the echo, or reflected sound is most perfect. Sound proceeding from the center of a circle is reflected to this point, hence in a large, circular room, we may expect in the center, a powerful echo. The room should be large for this effect to be produced, because sound moves with such velocity that, in a small space, the reflected sound follows the direct sound so rapidly, that they blend together, and form but one. We shall notice this fact further, in treating of the velocity of sound.

489. An oval, or ellipse, has two centers, or *foci*,† one towards each end, as *a* and *b*, (Fig. 173); and the nature of a curve is such that sound, light, or heat, proceeding from either of the *foci*, as *a*, is all directed, after reflection, at the various points, *c*, *d*, *e*, to the other focus, *b*. A whisper uttered in one focus of an oval room, may,

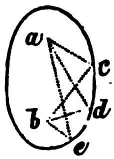
* A central point.

† The plural of *focus*.

488. Reflection from plane, convex, and concave surfaces. **Describe the** *effect of sound falling upon a smooth concave surface.*

489. Sound reflected from an oval. Whispering gallery. Ancient oracles Fable of Echo.

Fig. 173.

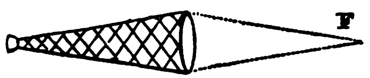


therefore be audible to a person situated at the other, though it may not be heard by persons placed between these two points. The celebrated whispering gallery of St. Paul's cathedral in London, is an example. By a knowledge of this property of sound, the ancient priests were assisted in imposing upon the people their own words as the oracles of the gods.

By the poets of antiquity, Echo was fabled as a wood nymph, who pined away for love, so that nothing remained of her but her voice. The grotto, the cavern, and the mountain side, were considered as the peculiar haunts of Echo. Every lover of nature is pleased in his rambles to find himself accompanied by Echo, who, in softer and sweeter tones, reflects his own accents. A great musical composer said that Echo was the best schoolmistress; "for, let a man's music be ever so good, by playing to her, she would teach him to improve it."

490. The *speaking trumpet* is constructed on a well known principle, viz: that sound may be heightened by reflection. The voice, instead of being dispersed in the open air, is confined within a tube, and the vibrations falling against its sides, are reflected and combined with those which are moving forwards, and thus concentrated, all move on to the point towards which the voice is direcied. The lines within the tube, (Fig. 174,) represent the manner in which sonorous vibrations are propagated; F represents the focus, or that point in which the waves of sound unite and are most intense. The speaking trumpet is of great use at sea, enabling the commander of a vessel to make his voice heard amidst the "sound of many waters," and in the most violent tempests.

Fig. 174.



491. The *ear-trumpet* is wider where the sound enters, than where it is applied to the ear; its sides are so curved, that, according to the law of reflection, all the sound which enters, is brought to a focus in the narrow end. The intensity of sound is thus greatly increased before it reaches the ear, and the deaf, by means of this invention, are enabled to enjoy the conversation of friends.*

* It is of late found that tubes of Indian rubber answer even a better purpose than the common ear-trumpet. From the nature of this substance, tubes may be made of a much greater length than could be conveniently used, if formed of an inflexible material; and it is ascertained, that the longer

490. Speaking trumpet.
491. Ear-trumpet. Shell ear-trumpet.

Some sea shells, from their concave, polished surfaces, are remarkably adapted to collect and concentrate the waves of sound. When properly fitted with a small tube, a shell of this kind forms an elegant and useful ear-trumpet. The resonance of sound within a large sea shell, is often a cause of wonder to the young, who are ready to fancy they hear within it, the roaring of that distant ocean of which it was once an inhabitant.

Velocity of Sound.

492. Sound, though it moves with great velocity, is less rapid in its progress than light. The lightning is seen before the thunder is heard, though the same electrical discharge is the cause of both. The flash of a gun is seen before the report is heard. The axe of the distant laborer may be seen to fall, before the sound of the blow is heard.

493. It is ascertained that sound moves through the atmosphere at the rate of 1142 feet (nearly a quarter of a mile) in a second. We may determine the distance of a thunder-cloud, by noticing the number of seconds which elapse between the lightning and the thunder. Since the pulse of a healthy person beats about once in a second, each pulse will indicate a distance of about a quarter of a mile. Thus, sixteen beats between the lightning and the report, would indicate a distance of about four miles, thirty two beats eight miles, &c. The distance of a ship at sea may be determined, by observing the time which passes between the flash of a gun fired from it, and the report of the same. The quickness with which an echo is returned, may also serve for a measure of distance. Thus, suppose a cliff upon the opposite bank of a river to return an echo in one second; as sound travels 1142 feet in a second, the breadth of the river must be half this distance, or 576 feet; since one second elapses while the sound is going and returning.

Music.

494. The natural music of birds, and the power of singing, or producing agreeable notes by the human voice, led, in the course

the conducting tube, the more intense is the sound. Thus, M. Biot, of Paris, found that aqueduct tubes a mile in length, conducted the most feeble sounds, so that according to his expression, "the only way to prevent being heard at the opposite extremity of the tube was not to speak at all."

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492. Sound moves with less velocity than light.

493. Distance of a thunder cloud ascertained by observing the time between the lightning and thunder. Ship at sea. Echo, a measure of distance.

494. Invention of musical instruments.

of ages, to the contrivance of stringed instruments, as the harp, guitar, &c.; and to the invention of wind instrument, as the flute, fife, &c.

495. In *stringed instruments*, as the harp and piano-forte, the air is struck by the string, and the vibrations of the air produce a corresponding sound in the ear; but, in *pipes*, as in the flute and organ, the air is forced against the sides of the tubes by the breath, and its vibrations or tones are produced by the reaction of the sides upon the air.

496. Sound is varied by the *rapidity* and *momemtum* of the vibrating body; and this vibration depends on the *length*, *tension*, and size of the string. A *short string* vibrates more quickly than a long one, and therefore *produces* the *sharpest* and *highest tones*; and a short and *small pipe*, from a like cause, *produces sharp tones*; and *large pipes*, *grave* and *deep sounds*. Savages early discovered this; and they made, and still make, simple instruments which please themselves and their wild companions. But art and science go further; they ascertain the causes of the pleasure derived from musical sounds, and thus proceed to complex inventions, in order to afford a higher gratification.

497. When an agreeable succession of simple notes having a perfect beginning and ending, is played or sung, the effect is called an *air*, or *melody*. When these notes forming an air, are combined with corresponding notes, in different octaves or on other instruments, and the whole is scientifically made to produce a concordant and agreeable effect, this is called *harmony*. The bass and treble of a piano-forte, played at the same time with the left and right hand, constitute the most common instance of harmony. Some of Handèl's pieces have been played by 1000 instruments and voices, all sounding harmoniously together.

The Human Voice.

498. Ancient physiologists considered the windpipe* as the immediate organ of sound, and that the voice was caused by the action of air against its sides, as sound is produced in musical pipes. But the ancients erroneously imagined this action of the air to be produced as it was passing *into* the lungs, or in the *inspiration* of the breath; whereas, it is now understood that the voice is formed during the *expiration* of air, or in its passage *from*

* Technically called the *trachea*.

495. Difference in stringed instruments and pipes.
496. Cause of the variety of sounds.
497. Melody and harmony.
498. Opinion of the ancients respecting the human voice. Their error. Office of the lungs.

the lungs. The lungs may be considered as performing the same office in propelling air into the windpipe, as the bellows of an organ in blowing air into the pipes of that instrument.

499. The organs which are essential to the production of vocal sound, are the *lungs*, *windpipe*, *larynx*, and *glottis*. Respecting the action of the *lungs*, and the effect of air upon them, we have previously made some remarks.* The *wind* or *air pipe*, is a cartilaginous tube, through which the air passes to and from the lungs; the *larynx* is an enlargement of the windpipe situated at the back of the mouth. Just below the larynx, is the *glottis*, a smaller passage furnished with muscles for contracting, enlarging, or altering its form, so as to produce a great variety of sounds. Indeed, it is principally to the powers of this small organ, that we attribute the phenomena of vocal sounds. If the windpipe below the glottis is perforated, so that the air, in expiration, issues at the orifice, there is no vocal power; but it is otherwise with an injury to the throat which does not affect the glottis.

500. Naturalists say, that even the windpipe and larynx may be taken from an animal without destroying its voice. Baron Cuvier asserts, that having cut off the head of a bird without injuring the glottis, the headless animal uttered several cries.—Some curious naturalists have experimented with the vocal organs of a pig, by fitting to the windpipe the bellows of an organ which answered the purpose of the lungs, and varying the aperture of the glottis by pressure with the fingers, have succeeded in imitating, with this apparatus, the grunting sound peculiar to that animal.

501. By observing the formation of the vocal organs in man, mechanicians have succeeded in constructing instruments which articulate letters, and even words and sentences. A German, who made himself famous for the invention of an automaton chess-player, is said to have succeeded in constructing a speaking machine which can talk in French and Latin. It is gravely suggested by some men of science, that from the discoveries made of the mechanism of the vocal organs and the nature of the human voice, it may be possible to construct machines for the pronunciation of modern languages, so that our language may be transmitted to the ear as well as to the eye of future generations.

502. But with all man's invention, he can never make a *living*, *breathing*, *thinking*, or *talking* machine. The greatest efforts of

* See Pneumatics, § 396.

499. Organs of sound.
500. Experiments with the vocal organs of animals.
501. Speaking machines.
502. Limited power of man.

human ingenuity, when compared with the productions of nature, are as the rude attempts of an unskilful hand in touching a musical instrument, to the perfection of a finished performer, who knows the exact powers of every key, and how to mingle sounds to produce a varied and melodious harmony. The imbecility of man must ever appear, when he directs his efforts into the region where God works, when he attempts to produce phenomena analogous to those of life. *Man may copy, but God only can create.*

PART VI.

OPTICS.

LECTURE XXXI.

LIGHT.—DEFINITIONS.—MOTION OF LIGHT.—ITS INTENSITY. OF REFLECTION, AND REFRACTION.

Preliminary Remarks on Light.

503. THE science which treats of *light* and its effects is called *optics*. This term is from the Greek, and signifies "*relating to sight*;"—the word *optics* signifies an organ of sight or *vision*.

504. So important is vision to man, that, as we should naturally expect, light and its phenomena early received the attention of philosophers. The science of optics is among the oldest branches of Natural Philosophy. Some of its most important principles were suggested by Plato and Aristotle. To the moderns, however, we are indebted for the invention of many of the most valuable optical instruments.

Philosophers have investigated the nature and effects of light, and poets have sung of its glories, but the enlightened christian, to philosophy and poetry, adds the homage of a devout and pious heart. He considers *whose spirit* it was that moved upon the dark and formless void;—*who* said "let there be light," and *who*, in view of the comfort and enjoyment it would bestow on his creation, pronounced this light to be "good."

505. The *nature of light* is not known. It is generally believed to be *matter*, since, in its motions, it obeys the laws which

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503. Definition of optics.

504. Antiquity of the science of optics. Reflections.

505. Nature of light. Newton's hypothesis respecting the nature of light. *Hypothesis* of Euler and others.

govern matter. Light is closely connected with heat and electricity, and there are some reasons for the belief that the three substances are but different modifications of the same principle.

Sir Isaac Newton supposed rays of light to consist of minute particles of matter, which are constantly emanating from luminous bodies, and cause vision; as orodiferous particles, proceeding from certain bodies, cause smelling. This is called the system of *emanation*. Some philosophers affirm that light is nothing more than the agitation of a medium called *ether*, which is far lighter and more subtile than air. They suppose that rays of light are produced by vibrations of air. One of the most celebrated advocates of the theory of *undulations and vibrations*, is Euler, who flourished in Germany, in the eighteenth century. But the beginner in science would profit little by attempting to enter a field of controversy, in which the greatest philosophers have found themselves wandering blindfold among luminous and opaque bodies, searching for light, but finding none. It is here as in other departments ef science, if we limit our inquiries to the *powers* and *qualities* of bodies, we find our toil amply rewarded; but if we attempt to lift the veil which God has interposed between us and the secret elements of which he formed matter, we find our grasp eluded, and our search confounded.

506. It is not the absolute *nature* of light which we are to investigate, but *the effects of light upon other bodies, and how light is affected by them.* To assist in determining how light affects other bodies, let us for one moment close our eyes; the instant void which succeeds, proves what would be the consequences of the *absence of light;*—we open our eyes and innumerable objects present themselves. The beauty and sublimity of nature, in its endless variety of form and color, would, but for the agency of light, exist for man in vain.

The manner in which *light is affected by other bodies*, involves some of the most important principles in optics, as *reflection* and *refraction.*

Definitions.

507. *Luminous bodies* are of two kinds; those which shine by their *own light*, as the sun, a lamp, or fire; and those which shine by *reflected light*, as the moon.

Transparent or *diaphanous** bodies are such as permit rays of light to pass through them. A perfectly transparent body is invisible. Air, when free from vapor of all kinds, is invisible. Water is not perfectly transparent, since it is visible, which is also the case with the clearest glass or gem. *Translucent* bodies permit light to pass faintly, but without representing the figure of objects seen through them, as China ware, and alabaster.

* From the Greek, *diaphanes*, signifying shining through

506. What are we to investigate in regard to light? How light affects other bodies, &c.

507. Luminous bodies. Transparent bodies. Translucent bodies. Opaque bodies.

Opaque bodies permit no light to pass through them, as wood, stone, &c. Such bodies reflect light, and by this means, not only render themselves visible, but diffuse light from luminous bodies around them, as the moon and planets.

508. A *ray* is a line of light. A *beam* is a collection of *parallel rays*. A *pencil* is a collection of *converging*, or *diverging* rays. A *medium* is any space through which light passes. A perfect vacuum is said to be a *free* medium. Air and glass are *transparent* mediums.*

Parallel rays are such as proceed equally distant from each other, through their whole course. *Converging rays* are such, as proceeding from any body, approach and tend to unite in a point in the form of a cone. *Diverging rays* are those which, proceeding from a point, continue to recede from each other, in the form of an *inverted cone*. A *focus* is that point at which converging rays meet.

Motion of Light.

509. 1st. Light moves in *straight* or right *lines*. Rays of light are projected from a luminous body in every direction, but always in *right lines*; these lines cross each other at every point, but the particles of which each ray consists, are so minute that the rays do not appear to be the least impeded by each other Wherever a spectator is placed with respect to a luminious body, every point of that part of the surface which is turned towards him is visible; this shows that the light is emitted in all directions. A ray of light passing through an apèrture into a dark room, proceeds in a *straight* line. We can *see* objects through a straight tube, though not through a curved one; but we can *hear* through a bent tube, which proves, that the radiation of light is not governed by the same laws as that of sound. Because light moves in straight lines, if a number of objects of the same height be placed in a row from the eye, the nearest one hides the others; as, for example, a row of trees, or a line of soldiers.

510. 2d. *Light moves with great velocity*. When a gun is fired, we see the flash before we hear the report, and lightning pre-

* The plural of medium, according to the Latin construction, is *media*, but when used in English, it seems proper to adopt the form of plural most common in our language.

508. A ray. A beam A pencil. A medium. Parallel rays. Converging rays. Diverging rays. Focus.

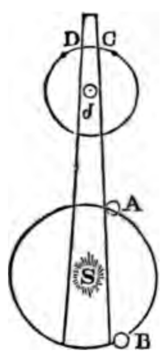
509. How does light move? Radiation of light not governed by the same laws as that of sound.

510. Velocity of light compared with that of sound. Velocity of light calculated by means of the eclipses of Jupiter's satellites.

cedes the thunder; these facts prove that light moves with greater velocity than sound. Astronomy has enabled men not only to foretell eclipses of the heavenly bodies, but, by means of these eclipses, to ascertain the rate at which light travels.

The rate at which light is propagated was discovered by Olaus Roemur, in making observations on the eclipses of the satellites of Jupiter. If the transmission of light were instantaneous, it must be obvious that the reflected light of the sun would take up no more time in passing from any of the planetary bodies to the earth, when they are farthest from us, than it does when they are nearest; and as the situation of the earth, with respect to the other planets, is different in different parts of her orbit, the satellites of Jupiter in emerging from the shadow of that planet, would be seen as quickly when the earth was in one part of her orbit, as in another. The planet Jupiter has four moons, which revolve about him as our moon revolves about the earth; they are subject to frequent eclipses, and from the same cause as that which produces eclipses of our moon, viz., the entering of the satellite into the shadow made by the primary; or, in other words, by the primary planet interposing between the satellite and the sun. By means of the telescope, an eclipse of one of Jupiter's satellites may be observed, with the time of its entering and emerging from the shadow cast by the planet. Astronomers calculate the exact moment of these changes as if viewed from the sun, S. But the earth and Jupiter are sometimes on the same side of the sun, and sometimes on opposite sides; in the latter case, the earth is farther from Jupiter by the whole diameter of its orbit, (or 190,000,000 of miles,) than when the two planets are on the same side of the sun. It is found by observation, that when the earth is nearest to Jupiter, an eclipse of one of his satellites is seen sooner, than when the earth is at its greatest distance from that planet. Let S represent the sun, A and B the earth in different parts of her orbit, *d* Jupiter, D his nearest satellite entering the shadow of that planet, and C the same satellite emerging from the shadow. When the earth is at A, the eclipse takes place about 8 minutes *earlier* than the calculated period, and when at the part of her orbit B, or most distant from the planet Jupiter, about 8 minutes *later;* that is, about 16 minutes of time elapse while light is traveling across the earth's orbit, 190,000,000 of miles, or from A to B. By an arithmetical calculation, we find, if light travels a distance of one hundred and ninety millions of miles in 16 minutes, it moves at the rate of about 197,916 miles in one second.*

Fig. 175.



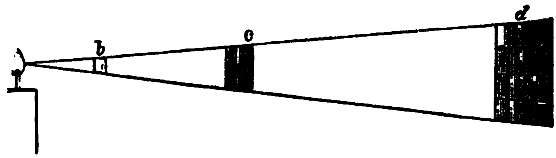
Intensity of Light.

511. Light diffused by a luminous body becomes fainter, *as the squares of the distance increase.* Suppose before the candle *a*, are placed three square boards, *b*, containing 1 square inch, *c* 4

* $190,000,000 \div 16 \times 60 = 197,916$.

511. Effect of distance upon light. Rule of calculating the diminution of light.

Fig. 176.



...are inches, and d 16 square inches. Let b be placed at the distance of 1 foot from the candle, c 2 feet, and d 4 feet. Here the smallest board b, will obstruct all the rays of light which would otherwise fall on c; and if b were removed, c would in like manner hide the light from d; now if the first board receive as much light as would fall on the second, whose surface is four times as large, the light must be four times as powerful, and sixteen times as powerful as that which would fall on the last board, because the same quantity of light is diffused over a space sixteen times greater. The light of a candle can be perceived, in a clear night, at the distance of one or two miles, if not obstructed by intervening objects. As sound within a certain distance *dies away*, and is lost in silence, so light insensibly *fades* into darkness.

Of Reflection, and Refraction.

512. The term *reflection*, as used in optics, signifies the rebounding of light from surfaces on which it falls. Here we see light following exactly the same laws as is common to all matter; thus affording a proof that it is, itself, a material agent. All bodies do not reflect light; it is only polished surfaces which have this property, and of such surfaces, some, as diamonds and glass may transmit, without reflecting light. *Mirrors* derive from reflection, their property of throwing back the image of an object.

513. *Refraction** denotes the bending of the rays of light, as they pass from the surface of one transparent medium to another. Thus, in passing from air into glass, all the rays, except those that fall perpendicularly, are turned from their straight course, or *refracted*. To the refraction of light we are indebted for the power of the *lenses*, or magnifying glasses, used in the manufacture of spectacles, telescopes, and microscopes. It is to the re-

* Refraction is so called from the Latin prefix, *re*, and *frango*, to break, on account of the broken appearance of a ray of light.

512. Reflection. Surfaces which reflect light.
513. Refraction.

n of light by the different lenses of the eye, that this or-ves its power of seeing.*

Inflection,† signifies the turning of rays of light from their course, by action of opaque bodies. If a beam of light be admitted through a perture into a dark room, and the edge of a knife be brought near the he rays of light, which would, otherwise, have proceeded in a straight ill be inflected, or turned towards the knife. On placing the edge of knife very near to that of the former, the stream of light divides in ldle and leaves a black stripe, indicating that all the light has been d from that space towards the two edges. As the knives are brought to each other, the dark stripe widens, till, upon the contact of the the whole light vanishes. Fringes of different colored light appear edges of the two knives, three separate fringes on each, and all vary-their colors; the first fringe beginning with violet and terminating d, the second beginning with deep blue and terminating with red, rd beginning with pale blue and terminating with pale red. As the ion of light in the rain-bow, is the effect of refraction, we may con-hat by inflection, the different colored rays being differently acted similar decomposition of light is produced. When we look at a with the eyes almost closed, fringes of light appear; the eyelids will case, cause the inflection of the beams of light which enter them.

we find that light may suffer a change of direction without actually ing on a body, but merely by coming *within the sphere of its influence;* body *gravitates* towards another, as the *needle is attracted by the* , and as one body in a different *electrical state* from another, is drawn s it.

inflection of light is rather to be regarded as a curious optical phe-on, than studied in relation to its bearing upon any known laws, or ant applications of science; but *reflection* and *refraction* are subjects must be attentively studied as the *two fundamental principles of*

LECTURE XXXII.

EFLECTION FROM MIRRORS.—PLANE MIRRORS.—CONVEX MIRRORS.—CONCAVE MIRRORS.

Angles of Incidence and Reflection.

5. A ray of light *turned back into the same medium* through h it fell, is said to be *reflected.*

*hough in accordance with the common use of language, we say, the es, it should be understood that the *seeing* is, in reality, in the mind, ich the eyes serve as spectacles.

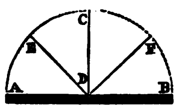
†rom the Latin verb *inflecto*, to crook, or bend in.

. Inflection. Light influenced by attraction.

. What is a reflected ray?

516. *Incident* * *rays*, are those which fall on the surface of a body; *reflected rays*, are those which are thrown from it. When a ray of light *falls perpendicularly* on an opaque body, it is reflected in the same line in which it proceeded; in this case, the *reflected ray returns* in the same path as that in which the *incident ray went*. But when a ray falls *obliquely*, it is *reflected obliquely;* that is, the reflected ray proceeds in a line on the oppositite side, as far from the perpendicular, as was the incident ray. The angle made by the incident ray, at the surface of the reflector, with a line perpendicular to that surface, is called the *angle of incidence;* the angle made by the reflected ray, with the same perpendicular line, is called the *angle of reflection*.

Fig. 177.



Suppose A B to represent a reflecting surface, C D, a perpendicular to this surface, E D the incident, and F D the reflected ray, the angle E D C is the angle of incidence, the angle F D C is the angle of reflection, and the *angles of incidence and reflection are equal.* Let a circle be described around the point D as a center; taking D E and D F for radii, it will be found that equal portions of circumference lie between E C and C F; this proves that the angles E D C and F D C are equal. And, again, since A D C is a quadrant, equally divided by the line E D, and B D C is a quadrant equally divided by F D, it follows that the angle A D E is equal to D B F, and the angle E D C is equal to F D C.

Reflection makes objects visible.

517. It is by the reflection of light that objects are made visible; while light itself, unless it fall directly upon the eye, is invisible. If a room be closed so that it is dark, except as a beam of light entering through a hole in the window-shutter gives a partial illumination, a bright spot may be seen on the wall opposite, and the course of the rays of light may be traced by means of the motes or small particles of dust floating in the air. Thus the agent which enables us to see all other things, remains itself unseen, and, like its great Creator, is known to us only by its effects.

* From the Latin *incido*, to fall upon.

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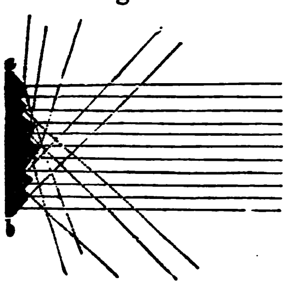
516. What are incident rays? How is a ray falling perpendicularly reflected? A ray falling obliquely. Angles of incidence and reflection. Equality of the angles of incidence and reflection.

517. Objects made visible only by the reflection of light.

The eye, itself, is not made sensible of the presence of light, till, after a certain series of operations upon its various coverings and humors, seeing is produced.

518. Smooth and polished surfaces reflect light most powerfully, producing, upon the eye, the images of the objects from which the light proceeded. Glass, which is transparent, or, in other words, transmits rays of light, by being rendered opaque, is made to reflect them. This is done by a metallic covering called an *amalgam* applied to one side. This amalgam interrupts the light in its passage from the glass into the air, turns back the rays, and throws them either directly in the incident line, or in an oblique direction. The reason why trees, rocks, and men are not all mirrors, reflecting other forms instead of their own, is that their surfaces are uneven.—Rays of light reflected from uneven surfaces are diffused in all directions. The parallel, horizontal lines in Fig. 178 represent the sun's rays, which striking upon the angular surfaces of the body *a b*, are diffused, as seen in the lines which cross the horizontal lines. If the reflecting surface be polished, although uneven it will be very brilliant, as in crystals, diamonds, and cut glass.—Here the effect is produced by the reflection of light from numerous polished angles.

Fig. 178.



Mirrors.

519. A *Mirror* is a smooth surface which reflects light. Thus a still lake, a polished plate of metal, and a looking glass, are mirrors. That department of optics which treats of the reflection of light by means of mirrors, is called *Catoptrics.**

Mirrors are of *three* kinds, the *plane*, *convex*, and *concave*.

A *plane mirror* is flat, or has its surface a perfect plane as in a common looking-glass. A *convex mirror* is globular, and reflects images from a rounded surface. A *concave mirror* is curved inward, and reflects light from a hollow surface.

* From the Greek *kataptron*, a mirror.

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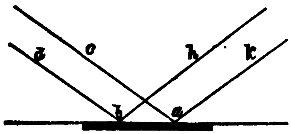
518. Surfaces which reflect light most powerfully. Light reflected from uneven surfaces.

519. A *mirror?* *What is* Catoptrics? Different kinds of mirrors.

The Plane Mirror.

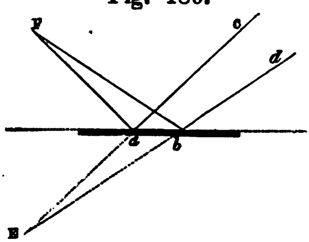
520. A common looking-glass is a *plane mirror*, composed of glass rendered opaque by a coating of tin and mercury. The rays of light having passed through the glass, are thrown back by the metallic surface; the glass is only necessary for preserv. this surface smooth and clear. Rays of light in passing through the glass, suffer some degree of refraction, and thus give a less perfect image than a pure, *metallic reflector.* For this reason, such mirrors are used in many optical glasses. The term *speculum* refers to a reflector which is metallic, or made of silver, tin, &c.; Mirrors are also called *specula.*

Fig. 179.



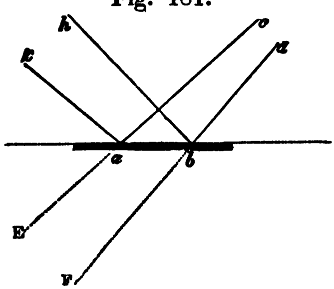
521. *Parallel rays falling obliquely on a plane mirror are reflected parallel;*—the rays *d b*, and *c a*, which are parallel, are reflected in parallel lines towards *h* and *k*.

Fig. 180.



522. *Converging rays are reflected from a plane mirror with the same degree of convergence;* *d b* and *c a* are convergent, and without the interposition of the mirror, they would unite in the point E; but being reflected, they unite in the opposite point F.

Fig. 181.



523. *Diverging rays reflected from a plane mirrors equally divergent;* *d b* and *c a* are divergent rays; if they had proceeded without interruption from the mirror, they would not have united at any point beyond it, as may be seen at E and F, because the tendency of divergent rays is to depart still farther from each other; falling upon the surface of the mirror, they are reflected towards, *h* and *k*, the lines of reflection being equally divergent with the lines of incidence.

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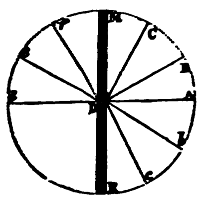
520. Common looking-glass. Speculum.
521. Parallel rays falling obliquely on a plane mirror.
522. Converging rays reflected from a plane mirror.
523. Diverging rays reflected from a plane mirror.

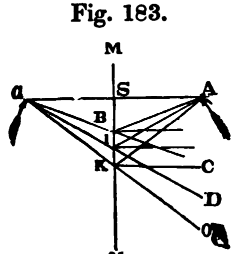
524. ***When an object is placed before a plane mirror an image is formed, which appears to be, as far behind the mirror, as the real object is before it.***

Fig. 182.



Suppose M R to be a *marble slab*, an *elastic ball* thrown from A, perpendicularly towards it at D, would rebound in the same line to A; but if thrown obliquely, as from B to D, it would move off to *b*, as far on the opposite side of the perpendicular, making the *angle* of *reflection* equal to the *angle* of *incidence*; if thrown from C, it would be reflected to *c*; and from any other point, the same law would govern the reflection. But suppose M R a *plane mirror*, and *light* to pass from an eye situated at A; the eye would see itself as if behind the mirror at *d*; or an eye at *b* would see an object situated at B as if it were at *e*; or an eye at *c* would see an object at C as if it were at *f*. The incident ray A D, and the reflected ray D *d*, or the incident ray A, and the reflected ray D *e*, form together what is called the *passage of reflection*, and this will, therefore, make the real distance of an image seen in the plane mirror, appear as far again from the eye as it really is; or, in other words, the image will appear as far behind the mirror, as the real object is before it. A person standing before a looking-glass, sees his figure as if behind the glass; if he walks towards the glass, the image will approach, but with double the real velocity, because both the incident and reflected rays are contracted by the movement. If he walks from the glass, the image seems to retire from him, with double his own speed.

Fig. 183.



525. Suppose an object A to be so situated in respect to the mirror M N, that the ray A B falling upon the mirror, is reflected to the line B C; let a perpendicular line be drawn from A to *a*, and extend the reflected ray B C, till it cuts the perpendicular at *a*, the distance *a* S is equal to S A, also every other ray proceeding from the object A will be reflected as if coming from behind the mirror at *a*. To an eye at O, the image *a* would appear as far behind the mirror, as the object A is before it.

526. An object which reflects light, is called a *radiant*; this radiant is, therefore, the point from which rays diverge, or the

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524. Apparent situation of the image formed by reflection from a plane mirror. Passage of reflection.

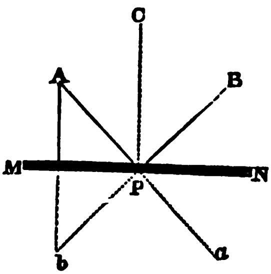
525. Why does the image seem to move with double velocity when a person approaches or recedes from a mirror?

526. Focus of divergent rays. Virtual focus.

focus of divergent rays, and the point behind a reflecting surface from which they *appear* to diverge, is called the *virtual* focus.

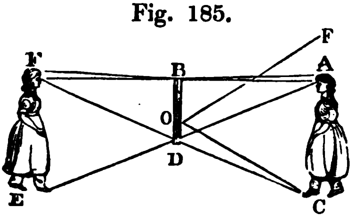
527. Since rays of light are reflected at the same angle as that at which they strike a reflecting surface, two persons may stand in such positions, that each can see the image of the other, in a mirror, without seeing his own. Suppose M N, to represent a mirror, A and B the positions of two persons with regard to it; the line P C is a perpendicular drawn from the surface of the glass at the point P, where the rays from A and B fall upon the mirror. The person at A, looking towards the mirror, would not see his own image, but that of him who stood at B, which would appear as if behind the mirror at *b*; in the same manner B would see A, as if standing at *a*.

Fig. 184.



528. *A person may see the whole of his figure in a plane mirror which is but half his height.*

Fig. 185.



Suppose B D to be a mirror half as high as the figure A C; the ray of light, A B, from the eye, falling perpendicularly on the mirror, is reflected back in the same line but the ray C D, from the foot, which falls obliquely, is reflected in the line D A. Since we view objects in the direction of the reflected rays which meet the eye, and as the image appears at the same distance behind the mirror that the real object is before it, the line A D must be extended to E, and the line C D to F, and here the image will appear to be situated.

But if the mirror is *less than half the height of the figure*, the whole of the figure cannot be reflected. Thus it may be seen in Fig. 185, that were the mirror only of the height of O B, the line C O from the foot of the figure, would be reflected in the line O F, above the eye.

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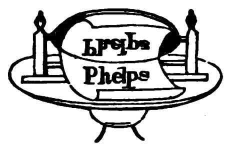
527. In what position may two persons see each the image of the other in a mirror without seeing his own?

528. How may one see an image of his whole figure in a mirror but half *his height?* Suppose the mirror to be less than half the height of the figure

529. An object viewed in a mirror appears *reversed;* thus the left foot of the figure A C, (see Fig. 185,) or the one which seems stepping forward, appears the right foot in the image F E; and when we stretch out our right hand, to take that of the image in a mirror, the latter seems to offer a left hand. By holding written or printed characters before a mirror, we perceive the effect of this *reversion*, in changing the image of objects from right to left. In the human figure there is, generally, great uniformity; the features on one side of the face being usually a very exact representation of those on the other; but where there is any peculiarity, as the nose a little turned to one side, or a squint eye, a man who should undertake to paint his own portrait would be in danger of reversing these traits, and making a caricature instead of a likeness. By reflecting an image from one mirror to another, the last reflection presents the object without being reversed, and written or printed characters appear as when seen without any reflection.

Fig. 186.



Convex Mirrors.

530. *Convex mirrors* reflect light from a *rounded surface*, as A B. Any polished, convex body is a mirror, as the spherical part of brass andirons with which children often amuse themselves in viewing their own miniature likenesses. The human eye is the most perfect of all convex mirrors, and so great is its power of diminishing objects and yet preserving their exact likenesses, that on a surface of less than half an inch in diameter, may, be represented a landscape, where men, animals, buildings, distant fields and hills, with mountains and clouds, are distinctly delineated.

Fig. 187.

531. Convex mirrors *disperse rays of light;*—they cause *parallel rays to diverge, converging rays to converge less, and diverging rays to diverge more.*

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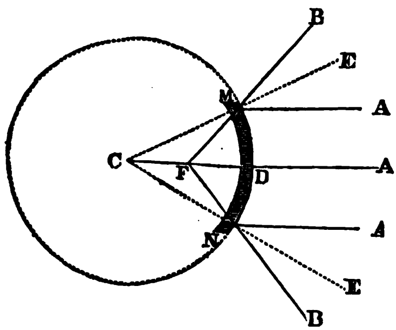
529. Image of objects seen in a reversed position.
530. What is a convex mirror? The most perfect convex mirror.
531. How do convex mirrors reflect rays of light? How does the figure illustrate this subject? What is the axis of a convex mirror?

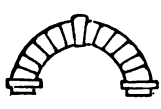
Fig. 188.



Let M N be a convex mirror, A M, A D and A N parallel rays falling upon it; if the mirror were flat, the rays would all be perpendicular to it, but as it is spherical, no ray can be perpendicular to it, which is not directed towards C, the center of the sphere. The ray A D is perpendicular to the supposed center, of which the convex mirror forms a part. Therefore A D, which falls perpendicularly, is reflected in the same line. But A M and A N, which fall obliquely, are reflected obliquely, in the direction M B and N B. The lines C E, which meet in the center of the sphere, and are therefore perpendicular to it, divide the angles of incidence and reflection, which may be seen to be equal. The image will be seen as at F, which is the point where the reflected rays, if continued through the mirror, would unite. This point, which is equally distant from the surface and center of the sphere, is called the *virtual* or imaginary *focus*.

The *axis* of a convex mirror, is a line passing through its center, as A C. (See Fig. 188.)

Fig. 189.



532. All spherical mirrors are curvilinear, that is, they are arcs, or segments of circles. Curves are formed of a number of straight lines, or *points*, infinitely short, and inclining to each other, like the stones in the arch of a bridge. Each of these points may be considered as a plane mirror, and the whole convex surface as consisting of innumerable small, plane mirrors, placed at angles with respect to each other, but forming a curve in their general arrangement. Such rays only as fall perpendicularly upon the

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532. Spherical mirrors curvilinear.

convex surface, or are directed towards its supposed center, will be reflected back in the same direction; all other parallel rays will fall obliquely upon it, and be reflected obliquely, according to the general law of reflection.

533. Suppose the rays *a b*, and *c d*, to be *parallel*, yet falling on the *convex* surface *d b*, they are, from their different points of incidence, rendered *divergent* in *h* and *e*, the angle of reflection with respect to each, being equal to the angle of incidence. Thus we see that convex mirrors render parallel rays divergent.

Fig. 190.

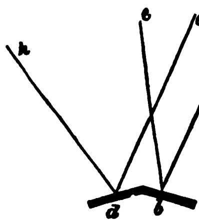
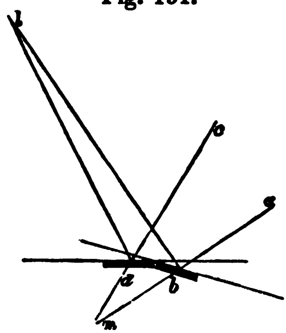
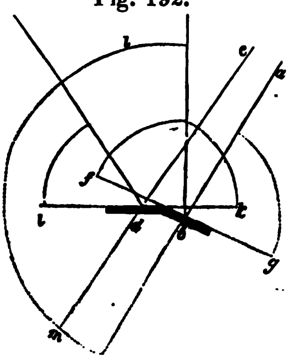


Fig. 191.



534. Again, suppose the rays *a b* and *c d* to be *convergent;* without the interposition of the reflector *b d*, they would unite at *m*, but they now proceed to unite in *l*, which is more distant from the reflecting surface than the point *m*. Here we see that convex mirrors cause converging rays to converge less.

Fig. 192.



535. Again, the *diverging* rays *a b*, and *c d*, which, without the interposition of the convex surface *b d*, would diverge but little at *m*, become, after reflection, much more divergent, as may be seen in the space *l;* and the angles of reflection will be found, in all these cases, exactly equal to the angles of incidence, if measured from the reflecting surface produced or lengthened, as at *f g* and *i k*.

536. *Convex mirrors represent objects smaller than they really are.* This is because the angle formed by the reflected ray, called the visual angle, is rendered more acute by a convex, than by a plane surface. Suppose the object C D placed before the convex mirror *a b;* the two rays C *e* and D *d*, which proceed from the extremities of the object, and which, if not in-

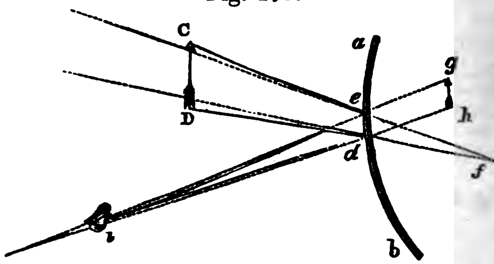
533. How can you prove that convex mirrors render parallel rays divergent ?

534. Illustrate the proposition that convex mirrors render converging rays less convergent.

535. Diverging rays falling on a convex surface.

536. Why do convex mirrors represent objects smaller than they are in reality.

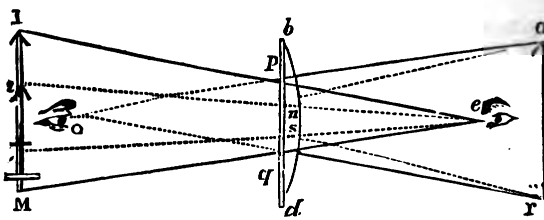
Fig. 193.



terrupted by the mirror, would converge at *f*, are reflected less convergent, and unite at *i*, forming an angle more acute than if they had not been reflected.

Again, objects appear *less* in a convex mirror, than in a common looking-glass, or *plane* mirror, because the convex surface reflects rays from points nearer to each other: "*Suppose the straight line *b d* to be a common mirror, and *a r* the object to be viewed; the ray from the point *a*, will be reflected to the eye situated at *e* from *p*, and the ray from *r* will be reflected from *q*; the image will appear at I M of the same size as the object would appear if viewed from the other side of the glass at *o*, because the angle *p e q* and the angle *p o q*

Fig. 194.



are equal. But when the same object is reflected from a convex surface, represented by the curved line, the reflections, from the top and bottom will take place from points nearer than before, viz., from *n* to *s*. The image is therefore reflected from the reduced space of *n s* instead of *p q*, and it will appear consequently, less than the object, as at *i m*. The angle subtended to the eye, by the reflection from the convex surface, is much less than that of the reflection from the plane mirror, and the difference in apparent size, of the two reflections will bear the same proportion as the space between *p q* bears to the space between *n s*."

537. 1st. As the visual angle is diminished by distance, *the farther an object is removed from a convex mirror, the smaller is the image reflected by it*

2d. Since the different points of an object are not equally distant from the surface of a convex mirror, the *image will appear curved.*

3d. As convex mirrors cause rays of light to diverge, *images appear nearer the surface of such reflectors than of plane mirrors.*

* Bakewell's Philosophy.

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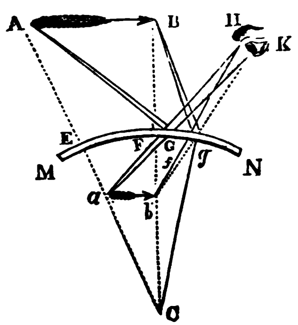
537. Enumerate three important laws with respect to images formed by convex mirrors. Explain Figure 195.

Fig. 195.



Let A B be an object placed before the convex mirror M N, in such a position that a reflected ray may enter the eye placed at H. From C draw C A, and C B, intersecting the mirror in E and F. The rays A F and A G, will be reflected to H and K, and will therefore enter the eye as if they came from *a*, at the point where the perpendicular A C, is intersected by the lines from F and G. Likewise B *f* and B *g* falling upon the points *f g*, will be reflected to the eye as if they came from *b*, the point where they intersect the perpendicular B C. The rays being thus rendered more divergent by reflection, they appear to come from *a b* nearer to the mirror, than A B, and since the extreme points *a* and *b* are nearer to each other than A B, the image will be represented of less size.

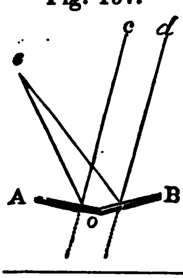
The greater the convexity of a reflector, the more will the images of objects be diminished, and the nearer will they appear to the surface.

Concave Mirrors.

Fig. 196.

538. *Concave mirrors* reflect light from a *hollow surface*, as E F. The concave mirror being, in form, the reverse of the convex, we find its powers essentially different, *Concave mirrors, collect rays of light* and *magnify objects*, while convex mirrors, *disperse* rays of light and *diminish* objects; plane mirrors *reflect* rays of light, without either enlarging or diminishing the visual angle, and consequently *represent objects of their natural size.*

Fig. 197.



539. *Concave mirrors render rays of light more convergent.*

The surface of a concave, like that of a convex mirror, may be considered as composed of numbers of points, or small plane mirrors; but, in the concave, these points are inclined towards each other, while in the convex, they lean in the contrary direction. Thus let A B, be one section of a concave mirror, and *c* and *d* parallel rays falling upon points on its surface; instead of being reflected parallel, as in the case of a plane mirror, or divergent as in a convex mirror, they *converge* and meet in the focus *e*, as they would do in the case of two plane mirrors leaning towards each other and meeting in the point *o*.

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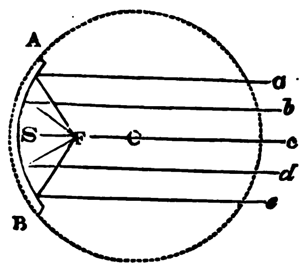
538. Concave and convex mirrors.

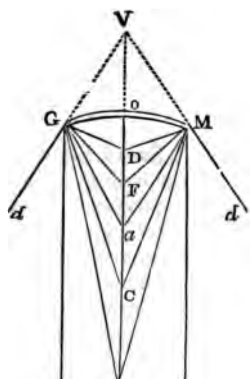
539. How is it proved that concave mirrors render rays of light more convergent?

Fig. 198.



540. Let A B represent a concave mirror, C is the *center of concavity*, or the center of the sphere of which the mirror is a section. *The line* F C c *passing through its center* is the *axis* of the mirror. F, is the *focus of parallel rays;* or that point before the mirror, where the *parallel rays a b c d* and *e* being reflected, meet. This focus is situated *half way* between the surface of the mirror S, and the center of concavity, C.

Fig. 199.



541. Again, let G M represent a concave mirror, C being the center of concavity; the *parallel rays f* G and *f* M will pass to the other side of the perpendiculars C G and C M, and meet at the focus of parallel rays F.

But when the incident rays are *divergent*, the focus is removed farther from the surface of the mirror. *If they diverge from a point more remote* than the center, as A G and A M, making a less angle with the perpendiculars than the parallel rays make, they will also make a less anglo on the other side of the perpendiculars, and meet in the point *a* between the focus and center. If rays diverge *from the center*, as C G, C O and C M, they will be reflected back to the same point C, because they are all perpendicular to the center. Rays which diverge from a point *between the center and a focus*, as from *a*, converge to a point V, on the other side of the center. *Rays diverging from the focus* F are reflected parallel as G *f* and M *f*.

Rays that approach the mirror *converging* as *d* G and *d* M, meet in a point between the focus and the mirror, as at D, they are reflected in the lines G *d* and M *d*, appearing to proceed from the point V behind the mirror, which point is called the *virtual* or imaginary focus.

542. " One who looks into a concave mirror sees his own face varied in the following manner. When he holds the reflector near his face, he sees his image *distinct*, because the rays come to the eye diverging (which is their natural state with respect to near objects and *enlarged*, because as the rays diverge less than before, the image is thrown back to a greater distance behind the mirror, than the object is before it, and the magnitude is proportioned to that distance. As he withdraws the eye, the image grows larger, and larger until the eye reaches the focus. From the focus to the center no distinct image is

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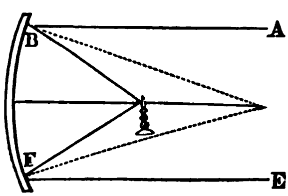
540. Show by the figure the center of concavity, &c. of a concave mirror.
541. What is proved by Fig. 199?
542. How may a person, viewing his image in a concave mirror, vary the *image by* a change of position?

seen, because the rays come to the eye converging, a condition incompatible with distinct vision. At the center, the eye sees only its own image, since the image is reflected back to the object, and coincides with it. Beyond the center, his face will be seen on the other side of the center before the mirror, (though habit may lead him to refer it to a point behind it,) and it will be *diminished*, being nearer to the mirror than the object is, and *inverted*, because an inverted image is formed when the rays are brought to a focus, and this becomes the object which is seen by the eye."*

543. The *sun's rays*, on account of the vast distance of that body from the earth, are considered as *parallel*; they converge to a point in the focus of parallel rays in concave reflectors. Even in so small and imperfect a reflector as a watch-glass, the focal point may, from the concentrated rays of the sun, become heated to such a degree as to inflame combustibles. Thus, watch-glasses are sometimes used to light tobacco pipes and kindle fires.— The word *focus* originally signified the *burning* point, or fire-place. The greater the concave surface and the more perfect the reflector, the more powerful will be its effect in concentrating the solar rays. Metallic concave mirrors have been manufactured of four or five feet in diameter; they are called *burning-mirrors*. The heat at the focus of such mirrors is sufficiently powerful to fuse metals, and even earths. The philosopher Archimedes, is said to have set fire to the Roman fleet under Marcellus, by means of a huge burning mirror. To do this he must have placed the mirror in such a position that the concentrated solar rays were reflected directly upon the ships of the enemy.

544. It has been shown that when the *incident rays are parallel*, the reflected rays converge to a focus. On the contrary, when the incident rays proceed from a focus, or *are divergent*, they are reflected parallel; thus let a burning taper be placed in the focus of a concave mirror; the ray which falls in the direction of the axis of the mirror, is reflected back in the same line, but the rays which fall at B and F are reflected to A and E, the dotted lines being the perpendiculars which separate the lines of incidence and reflection, and show their angles to be equal. Or, in other words, the diverging rays, B and F, are reflected parallel. This dispersing of divergent rays, is the reverse of collecting parallel rays into a focus, as is done by means of burning-glasses.

Fig. 200.



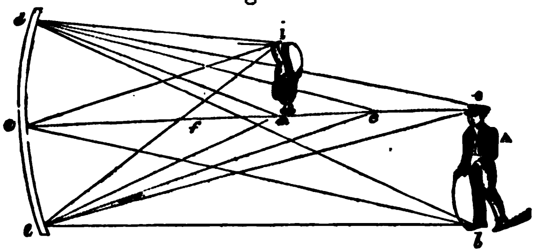
* Olmsted.

543. Heat produced by concentrating solar rays in small reflectors. Meaning of the word focus. Burning-mirrors.

544. Dispersion of rays proceeding from a focus.

545. It is only when an object is nearer to a concave mirror than its center of concavity, that its image is magnified; for when the object is farther from the mirror, the image will appear less than the object, and in an inverted position. Suppose a person, A, stand before a concave mirror below its axis *a c*

Fig. 201.



and beyond its center of concavity *c*. A ray of light *b a*, proceeding from the feet would fall upon the mirror at *a*, and be reflected to *i*, on the opposite side, at an equal angle from the axis *a c*. The rays *b e* and *b d*, also proceeding from the feet, are reflected in the lines *e i* and *d i*, and an image of the feet appears at *i*. The rays from the head of the person diverging in like manner in all directions, proceed to the points *e* and *d*, from whence they are reflected in the dotted lines to *m*, where appears an image of the head. Rays proceeding from other parts of the body, will also be reflected in their proper positions between *m* and *i*, where an inverted and diminished image of the whole figure appears. This image is beyond the focus *f* of parallel rays, because of the diverging of the incident rays, and the greater this diverging the more distant will be the image from that focus. "Thus if a man place himself directly before a large concave mirror, but farther from it than its center of concavity, he will see an inverted image of himself in the air between him and the mirror, of a less size than himself, and if he hold out his hand towards the mirror, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk when his hand is in the center of concavity, and he will imagine he may shake hands with his image. If he reach his hand further, the hand of the image will pass by his hand, and come between it and his body; and if he move his hand towards either side, the hand of the image will move towards the other, so that whatever way the object moves, the image will move the contrary way. This appearance of the image in the air between the mirror and the object, has been productive of many deceptions, which when exhibited with art, and an air of mystery, have been a source of gain to public show-men. The images of objects have been exhibited in this manner so as to surprise the ignorant, and please the scientific."*

546. When we consider the various appearances produced by the reflection of light from plane, convex and concave mirrors, we need not be surprised that advantage has been taken of these natural phenomena by artful men to impose on the credulous. "The

* Imison's Elements.

545, Explain Fig. 201.

546. Impositions practised by means of optical phenomena. Union of religion and philosophy.

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547. We ...
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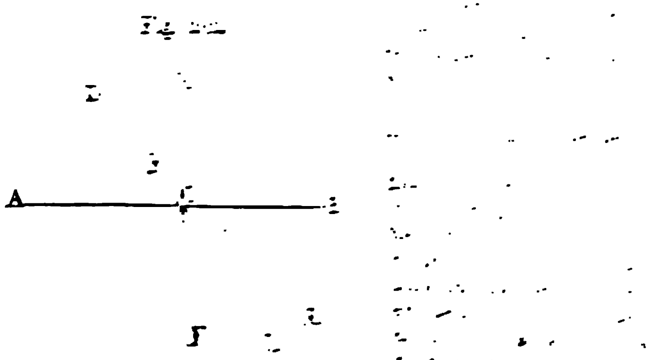
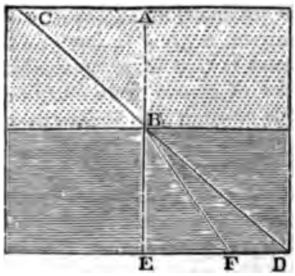


547. Light passing through ...

would be in the direction D K, *and recedes from it, either towards* L *or* O, *and this bending is called refraction.*

548. If light pass from a *rarer* into a *denser medium*, it is *refracted towards the perpendicular.*

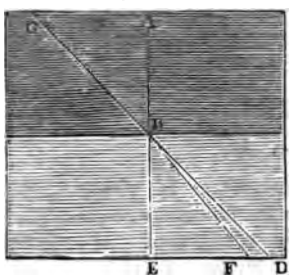
Fig. 203.



Suppose the ray C B to pass obliquely from *air* into a *denser medium, water.* The course of this ray through the air would be in the direction C B D, but as soon as it enters the water at B, it is bent towards the perpendicular A B E, and moves on towards F between B D and B E, making a *less angle* with the perpendicular, than if it had suffered no refraction.

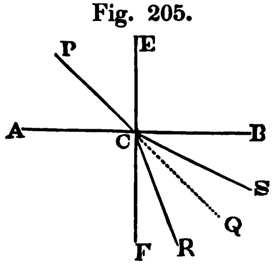
549. If light pass from a *denser* into a *rarer medium*, it is refracted *farther from the perpendicular.*

Fig. 204.



Let the upper part of the figure represent glass, and the lower part a *rarer* medium, viz., water; and let C B be a ray passing obliquely from the glass into water; on arriving at B, the surface of the rarer medium, the ray does not pass on in a straight line towards F, but is bent from the perpendicular B E, in the line B D, making a *greater angle* with the perpendicular than if it had suffered no refraction.

Fig. 205.



Let A B represent the surface which separates the two mediums, that from which the ray comes, and that into which it enters, this is called the *refracting surface.* The ray P C which falls upon it is called the *incident ray,* and the ray C R or C S is called the broken or *refracted ray;* and this, as we have shown, varies from the perpendicular E C F according as the refracting medium is more or less dense. The angle form-

548. How is light refracted when it passes from a rarer into a denser medium?

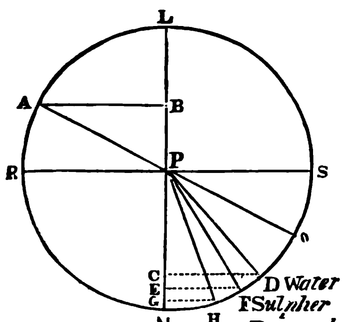
549. How refracted in passing from a denser into a rarer medium? Are *the angles* of incidence and refraction equal?

d by the incident ray P C, with the perpendicular E C, that is the angle P C E, is called the *angle of incidence*, and the angles formed by the refracted ray C R or C S with the perpendicular C F, that is the angle F C R or F C S are called *angles of refraction*. On account of the bending which the ray of light undergoes, the angles of refraction and incidence are never equal.*

Different Refractive Powers of Bodies.

550. Transparent bodies differ in their power of bending light: as a general rule, the refractive power is proportioned to the density. Thus, the refractive power of water is greater than that of air: the refractive power of glass is greater than that of water, and the refractive power of the diamond is greater than all. But the chemical constitution of bodies, as well as their density, is found to affect their refracting power. Newton first discovered that inflammable bodies possess this power in a high degree, and he even ventured to predict that water and diamond might have, in their composition, inflammable matter. This hypothesis, which appeared so visionary, at that day, has been proved by chemistry in the most satisfactory manner. Hydrogen, one of the constituents of water, is now known as one of the most combustible of all substances; and diamond, which is crystalized carbon, may be burned like charcoal.

Fig. 206.



Suppose a ray of light, A P, to pass from air into water. Instead of proceeding in a straight line to *o*, as it would if not refracted, it will be bent in the line P D. If, instead of water, the refracting medium be sulphur, a denser and more inflammable substance, the ray will be bent in the line P F. If the medium be diamond, the refraction will be in the line P H. The angle at which water refracts light, or the angle *o* P M, will be seen to be the greatest of all the angles of refraction, and the angle at which it is refracted by the diamond, or the angle H P M, is the smallest.

The angle of incidence, or the angle A P L, is the same in the different cases of refraction.

* Euler.

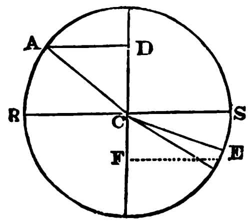
* This is proved by a reference to geometry: thus, producing the line P C to Q, (see Fig. 205,) the angles Q C F and P C E being *vertical*, are equal to

550. Bodies differ in their refractive powers. The refractive powers of bodies affected by their chemical constitution. Combustible substances proved to possess most refractive power. Explain Fig. 206. The sines of *the angles of incidence and refraction in the same ratio*. Total **reflection**.

Let a line A B, be drawn at the shortest distance of the point A from the perpendicular L P, this is the *sine* of the angle of incidence. In the same manner is found the *sine* D C of the angle of refraction of water; the *sine* E F of the refraction of sulphur, and the *sine* G H of the refraction of diamond.

It has been ascertained from many observations, that the sines of the angles of incidence and refraction are always in the same ratio; thus, from air into water, the sine of the angle of incidence is to the sine of the angle of refraction nearly as 4 to 3, whatever be the position of the ray with respect to the refracting surface. From air into sulphur, the sine of the angle of incidence is to the sine of the angle of refraction as 2 to 1; from air into diamond as 1 to $\frac{2}{5}$.

Fig. 207.



Let A C be the ray incident upon the rarer medium R S. It will be refracted from the perpendicular D F into the direction C E, so that the sine A D is to E F in a constant ratio.

A ray of light cannot be refracted, whenever *the sine of the angle of refraction becomes equal to the radius of a circle.* Thus, if we increase the angle A C D, the angle F C E will be also increased, till the lines C E and F E coincide with, or fall upon the radius C S. But if beyond this position of the ray A C, the angle A C D is still farther increased, it is manifest that its sine also is increased; and consequently, in order that the ratio between the sines may be constant, the sine of refraction E F, must also be increased, which is impossible, since we have already supposed it equal to the radius C S.

Thus light falling *very obliquely* upon a transparent medium ceases to be refracted; but the incident rays are all *reflected.* This is called *total reflection.* Since the brightness of the reflected image depends upon the quantity of light and in ordinary cases of reflection a portion of light is absorbed by the reflecting substance, those images which arise from total reflection are by far the most vivid.

Familiar Examples of Refraction.

551. 1st. An oar with one end in water appears bent, and also somewhat shorter than it really is. The rays of light from the

each other, according to the 15th problem of Euclid's 1st Book. The angle Q C F then, is equal to the angle of incidence P C E; therefore the angle of refraction R C F or S C F is greater, or less. There are then only two cases which can exist; the one in which the refracted ray being C R, the angle of refraction R C F is less than the angle of incidence P C E; and the other, in which the refracted ray being C S, the angle of refraction S F C is greater than the angle of incidence P C E. In the former case, we say that the ray C R approaches the perpendicular, C F; and in the other, that the refracted ray, C S recedes or deviates from the perpendicular.

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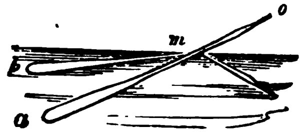
551. Why does an oar appear bent in water? Why does a river, under certain circumstances, appear more shallow than it is? Different appearances of the bottom of a river when viewed perpendicularly and obliquely. Example of an object at the bottom of a cup, seen through water. Gold-fish in a glass globe.

immersed part of the oar proceeding from a denser to a rarer medium, are refracted *from* the perpendicular, and inclined towards the eye of the spectator. Let *o m a* represent an oar, the part *m o* being in the air, and *m a* in the water; the rays diverging from *a*, will appear to diverge from *b*, nearer to the surface of the water; every point in *m a* will seem nearer to the surface than it is in reality, and the part of the oar at *m a'* will appear to make an angle with the part *m o*.

Fig. 208.

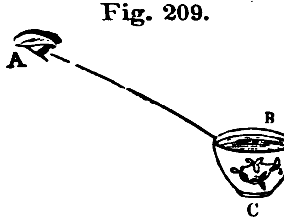


2d. The bottom of a river when viewed obliquely appears nearer to the eye than it actually is; for this reason the water does not seem as deep as it is in reality. Persons in bathing are sometimes thus deceived, and lose their lives in consequence of venturing in water beyond their depth.

3d. When we look from a boat perpendicularly into the water of a river, we see the bottom in its true place, because there is no refraction. But the more obliquely we view an object seen through a transparent medium, the more its position seems changed.

4th. Take a cup which has the picture of a flower (or other figure) at the bottom, and hold it in such a position that the object is not visible to the eye at A, being just concealed by the top of the cup; without changing the position of the eye or the cup, let the latter be filled with water and the flower will now be seen as if at B, although the real object is at C.

Fig. 209.



5th A gold-fish in a glass globe filled with water, sometimes appears as two fishes, being seen both by light bent through the surface of the water, and by straight or perpendicuiar rays passing through the sides of the glass. In order to see bodies under water in their true places and in their true positions, the eye should view them through a tube, the farther end being closed by a plate of glass, and held in the water.

552. The atmosphere is a transparent body, becoming more dense in proportion as it is nearer the surface of the earth. The *different strata of air, having different degrees of density, vary in their refractive powers.* In considering the subject of Acoustics we found the atmosphere to be the great conducting medium

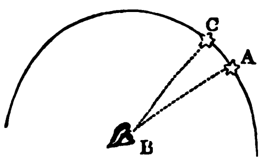
552. Different refractive powers of atmospheric strata. In what respects the atmosphere affects light.

by which sound is propagated. This medium has a no less important effect on light, in its *transmission*, *refraction*, and *decomposition*.

553. The heavenly bodies appear higher than they really are, because the rays of light, instead of moving through the atmosphere in straight lines, are continually bent towards the earth in consequence of meeting with different mediums which become denser as they are nearer to the earth. It is supposed that beyond the atmosphere which surrounds our globe, there is, if not a vacuum, an atmosphere of a highly rarefied nature, called *ether*. It is proved that the refractive power of the atmosphere is greatest at the earth's surface, and diminishes upwards.

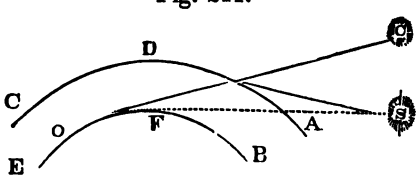
554. The figure represents the difference in the *real* and *apparent* situation of the star A. Rays of light falling thus obliquely on the earth, would be refracted in a curve, as in the line A B, and seen in the direction of a tangent to that part of the curve which meets the eye, B C. Thus, the apparent altitude is C B. This distance between A and C is called the *parallax* and is of great importance in astronomical calculation.

Fig. 210.



It is owing to their parallax that the moon and stars appear above the horizon before they have actually risen, and are seen after they have set. The day is lengthed from this cause; for while the sun is yet below the eastern horison, he is visible by means of his refracted rays, and his light lingers some moments after he has sunk beneath the western horizon.

Fig. 211.



555. Suppose F B to represent the earth's surface, and G D A the atmosphere. The sun at S would appear to a spectator at O as if situated at C. The distance between the real and apparent situation of the sun would lessen until the sun would be in the ze-

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553. Why the heavenly bodies appear higher than they really are.

554. Real and apparent situation of a star. Parallax. Effects of the parallax of the celestial bodies.

555. Explain the effect of the atmosphere upon the sun's rays.

th, or directly over the observer, when, as the rays fall perpendicularly, there would be no refraction. The stratum of air which the sun's rays must penetrate, in the horizon, is so much thicker and denser than in the zenith, that the light is diminished more than 1300 times in passing through it. It is this that renders the rays of the sun, at his rising and setting, so much less dazzling to the eye than when he is vertical.

556. "The loss of light, and consequently of heat, by the absorbing power of the atmosphere, increases with the *obliquity of incidence.* Of ten thousand rays falling on its surface, 8123 arrive at a given point of the earth, if they fall perpendicularly; 7024 arrive if the angle of direction be fifty degrees; 2831, if it be seven degrees; and only five rays will arrive through a horizontal stratum. Since so great a quantity of light is lost in passing through the atmosphere, many celestial objects may be altogether invisible from a plain, which may be seen from elevated situations. Diminished splendor, and the false estimate we make of distance, from the number of intervening objects, lead us to suppose the sun and moon to be much larger when in the horizon than at any other altitude, though their apparent diameters are then somewhat less. Instead of a sudden transition from light to darkness, the reflective power of the air adorns nature with the rosy and golden hues of the aurora and twilight. Even when the sun is eighteen degrees below the horizon, a sufficient portion of light remains to show that, at the height of thirty miles, it is still dense enough to reflect light. The atmosphere scatters the sun's rays, and gives all the beautiful tints and cheerfulness of day. It transmits the blue light in the greatest abundance; as we ascend higher, the sky assumes a deeper hue, but in the expanse of space, the sun and stars must appear like brilliant specks in the profound blackness."*

Singular Appearances caused by unusual Refraction, or by Total Reflection.

557. To *unusual* or *extraordinary refraction*, are referred certain phenomena, caused by the *unequal density* of different portions of *the atmosphere.* We have shown that the incident ray, by falling very obliquely, causes *total reflection*, instead of refraction. Both these causes may be concerned in the production of certain appearances, which in a less philosophical age were regarded as the effect of magic. The elevation of coasts, ships, and moun-

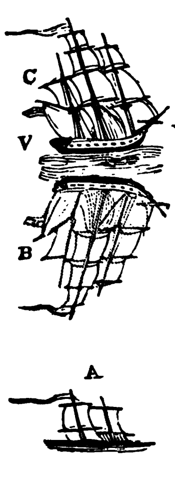
* Mrs. Somerville's "Connection of the Physical Sciences."

556. What effect has obliquity of incidence upon polar light and heat? Why do the sun and moon appear largest at the horizon? Probable appearance of the sun and stars beyond the earth's atmosphere.
557. Looming, mirage, &c.

tains, above their usual level, when seen in the distant hori called *looming*. The French have given to the same class nomena, the name of *mirage;* and the Italians, who are no customed to them in the Straits of Messina, call them th *Morgana.*

When the rising sun, says an Italian writer, throws his an angle of 45° on the sea of Reggio, and the water in the calm and unruffled, a spectator on an eminence above t who places his back to the sun and his face to the sea, see upon the surface of the water, castles, arches, columns and palaces and churches, with balconies and domes; valli plains covered with herds and flocks; men walking and and a variety of strange and grotesque figures, rapidly suc each other. When the atmosphere is charged with vap exhalations to the height of about twenty feet, the same with less distinctness of outline will appear in the mists and floating in the atmosphere, as if suspended there. This a presentation of the objects on the opposite coast, as first de in 1793 was scarcely credited, until subsequent statements that others had observed similar appearances in other pla

Fig. 212.



558. In 1798, at Ramsgate, England, a shi served, which appeared as at A, the top-mast only part which was seen above the horizon. verted image was seen at B just above the re and finally an erect image at C. The sea w at V W. As the ship A rose to the horizon,* C gradually disappeared, and the image B towards A. After the whole ship was above zon, the two images B and C were distinctly

An English captain at sea, knew a ship by ed image in the air, when the ship itself was horizon, or entirely out of sight. "It was," "so well defined that I could distinguish b scope, every sail, the general rig of the ship, a ticular character, so that I confidently pron my father's ship, the Fame, which it afterwa to be, though in comparing notes with m found that he was about 30 miles distant, a teen miles beyond the horizon."

559. "Let S F be a ship in the horizon, a to the eye at E, by rays S E, F E procee straight line to E, through a tract of the atm its usual state. If we suppose that the refract of the atmosphere above the line S *a* E varie be less at *c* than at *a*, then rays S *d*, F *c* proce wards from the ship, and which could not in

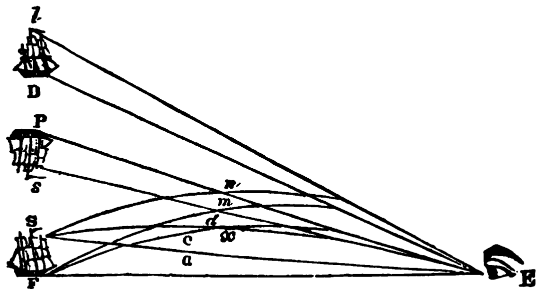
* The pupil will recollect that owing to the rotundity of the top of an approaching ship at sea is the part first seen.

558. The ship Fame known by its aerial image.
559. Aerial representation of a ship.

nary state of the air, reach the eye at E, will be refracted into curve lines F c, S d; and if the variation of refractive power is such, that these last rays cross each other at x, then the ray S d, in place of being the uppermost, will now be the undermost, and, consequently, will enter the eye as if it came from F.

If we now draw lines E s, E P, tangents to these curve lines at E, these lines will be the direction in which the ship will be seen by the rays F c, S d, and the observer at E will see an inverted image P s of the ship S F considerably elevated above the horizon. The refractive power of the air still continuing to di-

Fig. 213.



minish, other rays, S n, F m, that never could reach the eye at E in the ordinary state of the atmosphere, may likewise be bent into curves which will not cross each other before they reach the eye at E. In this case, the tangent E l, to the upper curve S n E, will be uppermost, and the tangent E D, to the lower curve F m E, lowermost, so that the observer at E will see the erect image D l, of the ship above the inverted image. It is possible that a third, and even a fourth image may be seen by similar refractions."*

560. The *mirage* is common in hot climates on sandy plains. In the middle of the day when the sun shines on the level surface of the sand, the appearance of a sheet of water is observed at a little distance; and so complete is the deception, that any person ignorant of the cause, would not doubt but he was approaching a lake or river. This spectral body of water reflects the animals, trees or mountains around, with great distinctness. As the traveler, perhaps fainting with thirst, advances, the tantalizing phantom of water recedes, exhibiting on its surface new images of surrounding objects. A traveler in India thus describes a phenomenon of this kind. "A deep precipitous valley below us, at the bottom of which I had seen one or two miserable villages in the morning, bore, in the evening, a complete resemblance to a beautiful lake; the vapor which played the part of water, ascend-

* Treatise on Optics—Library of Useful Knowledge.

560. Deceptive appearances by means of the mirage. Mirage described by a traveler in India. Supposed cause of the mirage. Appearance witnessed by Dr. Buchan at Brighton.

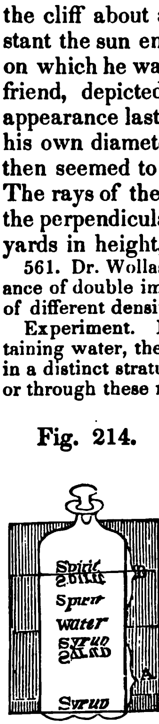
ing nearly half way up the sides of the vale, and on its bright surface trees and rocks were distinctly reflected."

Some writers attribute the mirage chiefly to partial, or total reflection of the rays of light at the surfaces of atmospheric strata of different densities. The following occurrence which happened in November, 1804, is supposed to have been produced by a similar cause. "Dr. Buchan, while watching the rising sun from the cliff about a mile to the east of Brighton, England, at the instant the sun emerged from the surface of the ocean, saw the cliff on which he was standing, a wind-mill, his own figure, and that of a friend, depicted immediately opposite to him, on the sea. This appearance lasted about ten minutes, till the sun had risen nearly his own diameter above the surface of the waves. The whole then seemed to be elevated into the air and successively vanished. The rays of the sun fell upon the cliff at an incidence of 73° from the perpendicular, and the sea was covered with a dense fog many yards in height, which gradually receded from the rising sun."

561. Dr. Wollaston has proved, by simple experiments, that the appearance of double images is owing to the refraction of rays through mediums of different densities.

Experiment. If you pour some spirits of wine or alcohol in a bottle containing water, the spirits of wine, unless the water is agitated, will remain in a distinct stratum at the top; on looking at any object behind the bottle, or through these mixed strata, an inverted image of the object will appear.

Fig. 214.



Syrup is more dense than water, therefore the same effect will be produced by looking at an object through strata of syrup and water. Dr. Wollaston poured into a square phial a small quantity of clear *syrup*, and above this he poured an equal quantity of *water*, which gradually combined with the syrup, as seen at A. The word *Syrup* upon a card held behind the bottle, appeared erect when seen through the pure syrup, but inverted, as represented in the figure, when seen through the mixture of water and syrup. Dr. Wollaston then put nearly the same quantity of *rectified spirit of wine* above the *water*, as in the figure at B, and he saw the appearance there represented, the true place of the word *Spirit*, and the inverted and erect images below. By looking along a red hot poker at a distant object, an erect and an inverted image is seen. This is in consequence of the change produced in the density of the air produced by the heat. The air nearest the heated poker being most rare, its refractive power is least.

562. "We have no doubt," says an English writer, "that some of the facts ascribed in the Western Highlands of Scotland to second sight, have been owing to the unusual refraction of the atmosphere, and that the same cause will explain some of those wonders which sceptics discredit, and which superstitious minds attribute to supernatural causes. The beacon-keeper of the

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561. Experiments by Dr. Wollaston with refracting mediums of different densities.

562. Strange appearances accounted for by unequal refraction.

e of France, who saw ships in the air before they rose above the visible rizon, may now recover his good character in the eyes of the former, while e latter may cease to regard him as a magician." Our country has its superstitious legends of wonderful sights, attested by veritable witnesses. The *hantom Ship* of the Puritans, and the Flying Dutchman of the settlers of ew Amsterdam, were probably *real apparitions*, for we find that *unequal refraction* may cause a ship to appear as if suspended in the clouds, or produce the phantom of a ship, while the real object is out of sight.

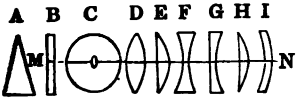
LECTURE XXXIV.

LENSES.

563. Glass, in various forms, is the substance most used for refracting the rays of light in optical experiments, and for optical instruments.

1st. An *optical prism*, A, is a solid, having two plane surfaces A R, A S, inclined to one another, these are called its *refracting surfaces*. 2d. A *plane glass*, B, has two plane surfaces parallel to one another. 3d. A *sphere* or spherical lens, C, has every point in its surface equally distant from a common center, O.

Fig. 215.



4th. A *double convex lens*, D, is bounded by two *convex* spherical surfaces, whose centers are on opposite sides of the lens. When the radii of its two surfaces are equal, it is said to be *equally convex;* when the radii are unequal, it is said to be *unequally convex*.

5th. A *plano-convex lens*, E, is bounded by a plane surface on one side, and a convex one on the other. 6th. A *double concave lens*, F, is bounded by concave surfaces on both sides. 7th. A *plano-concave lens*, G, is bounded by a plane surface on one side, and a concave on the other. 8th. A *meniscus*, H, is bounded by a concave and a convex spherical surface; and these two surfaces meet if continued. 9th. A *concavo-convex lens*, I, is bounded by a *concave* and a *convex* surface; but these two surfaces do not meet though continued.

The axis of these lens is a straight line, M N, in which are situated the centers of their spherical surfaces, and to which their plane surfaces are perpendicular.

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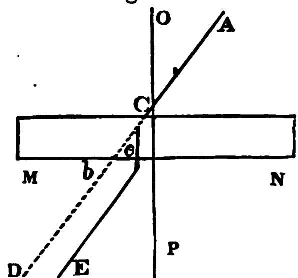
563. What substance is most used in optical experiments? Prism. Lenses. Axis of the lenses.

Fig. 216.

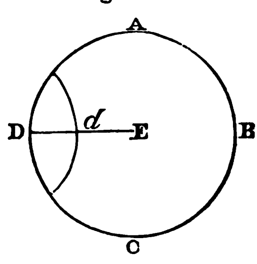


564. The most simple case of refraction is, when the refracting substance is terminated by plane surfaces, parallel to each other.—Suppose M N to be a piece of glass, terminated by plane surfaces, and that the ray A C falls obliquely at the point C. On entering the glass, the direction of the ray will be bent out of the straight line C D, and will move *towards* the perpendicular O P, through the glass, in the line C *e*. On leaving the glass, the ray is again refracted, but in a contrary direction; or *from* the perpendicular O P towards D. A ray, therefore, passing obliquely through a transparent body of parallel surfaces, has its course turned from the original direction, but, after refraction, proceeds in a line parallel with that direction; thus, E *e* is parallel with *b* D. This refraction takes place in the light which passes through glass windows; but owing to the thinness of the panes, the *apparent* varies little from the *true* situation of the objects thus seen. When the two surfaces of a pane of window glass are not planes, or are not perfectly parallel to each other, objects seen through the glass appear more or less distorted.

565. A *lens** is usually of glass, ground into such a form as to collect or disperse the rays of light which pass through it.

A *convex* lens *collects*, and a *concave* lens *disperses* rays of light.

Fig. 217.



The *sphere* of a lens is an *imaginary* circle, of which its surface is a portion. The circle A B C is the sphere of the convex lens D.

The *radius* of a lens is the radius of its sphere, D E; and a line D *d* passing through its center, is its axis.

566. The *focus* is a point beyond the convex lens where the refracted rays meet. This point depends upon the form of the lens, and the refracting power of the substance of

* From the Latin, *lentil*, a bean. It was the double convex, to which the name lens was first applied. This has its two sides convex, like a bean.

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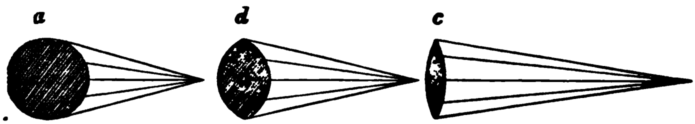
564. Cause of refraction when the refracting surface is terminated by plane, parallel surfaces. Refraction of glass windows.

565. Definition of a lens. Effects of a convex and concave lens upon light. The sphere of a lens. Radius of a lens.

566. Focus of a convex lens. What renders the focus more distant?

which it is composed. The less convex or bulging the lens is, the more nearly it approaches a plane glass, and consequently the more distant is its focus. The more convex or bulging a lens is, the more obliquely will the rays, at any distance from the center,

Fig. 218.

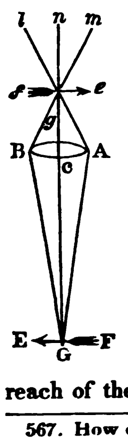


fall upon the surface; and the sooner, in consequence of their being more bent, will they meet the axis. Thus *a*, which is a sphere, would converge the rays sooner than *d*, and the latter would converge them sooner than the less convex lens *c*.

Convex Lenses.

567. Let A B be a *convex* glass, exposed to a distant object E F, whose rays G A, G *c*, G B fall on the glass, and passing through it, undergo a refraction, which will take place in such a manner, that the rays proceeding from the point G shall meet on the other side of the glass, in the point *g*. The same thing will happen to the rays which proceed from every point of the object. The refracted rays A *l*, B *m*, C *c*, will pursue the same direction as if the object were at *e f*, and inverted; and the object will appear as many times smaller as the distance *c g* shall be contained in the distance *c* G. Such a glass represents the object, E F, behind it, at *e f*; this representation is called the *image*, which is consequently inverted, and is smaller than the object, in proportion as *c g* is less than *c* G.

Fig. 219.

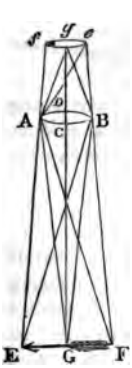


If the sun were the object, the image represented at *e f* would be the image of the sun; though very small, it would be so brilliant as to dazzle the eye, for all the rays which pass through the glass meet in this image, and therefore exercise an increased power of giving light and heat. Combustible substances placed in the focus of such a glass are instantly consumed. Metals are melted, and even vitrified by it; and other effects are produced far beyond the reach of the most active and intense fire. The reason for these

567. How does an object appear when viewed through a convex lens? Why would the sun's rays at *e f*, Fig. 219, be very intense? How does a convex lens differ from burning-mirrors?

effects is the same as in the case of the burning-mirrror. In both cases the rays of the sun diffused over the whole surface of the glass, are collected in the small space of the sun's image. The only difference is, that in the mirror the rays are collected by reflection, and in the convex glass by refraction.

Fig. 220.



568. *Second illustration of the appearance of objects represcnted by a convex lens.*

Let A B C D be a convex glass, before which is placed an object E G F. The rays which from the point E, fall upon the glass, are contained in the space A E B; and are all collected in the space A *e* B by refraction, so as to meet in the point *e*. In the same manner, the rays from the point G, which fall on the glass, and which fill the space A G B, are comprehended by means of refraction in the space A *g* B, and meet in the point *g*. Finally the rays from the point F, which fall on the glass in the angle A F B, are refracted so as to meet in the point *f*. Thus we shall have the image *e g f*, in an inverted position behind the glass; and as many times smaller than the object, as the distance D *g* is smaller than the distance C G.

In order to determine the place of the image *e g f*, we must attend as well to the form of the glass, as to the distance of the object. As to the first, it may be remarked, that the more convex the glass is, or in other words, the more the thickness of the middle C D, exceeeds that of the extremities, the nearer the image will be to its surface. With regard to the distance, if we bring the object E F nearer to the glass, its image *e f* retires from it. When the object, then, is very distant, the image falls in the very focus; and the nearer we bring the object to the glass, the farther the image retires from it, and that in conformity to a law in optics, by means of which we can always determine the place of the image for every distance of the object, provided we know the focus of the glass. The point where the rays meet is, as has been said, the place of the image. This point is easily found by experience. The different denominations of optical glasses are derived from it, as when we say, such a glass has its focus at the distance of an inch, another at the distance of a foot, another at the distance of ten feet, and so on; or more concisely, a glass of an inch, a foot, or ten feet focus.

569. To prove that a concave lens disperses rays of light, let A and C be rays falling upon the concave lens D E; instead of converging from *a* and *c* towards *b* in the axis of the lens,

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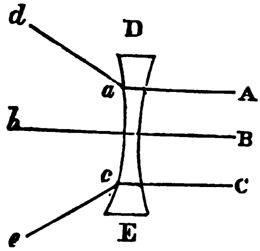
568. How is the subject of vision through convex lenses farther illustrated? What is meant by a glass of one inch or one foot focus?

569. Effect of a concave lens. How are convex and concave lenses used in connection?

Fig. 221.

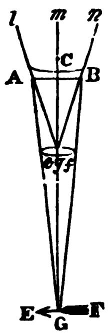


they will, diverge to *d* and *e*. A perpendicular ray B *b* passes on in a straight line without any refraction. It will be seen that, as the rays A C *diverge* on leaving the glass, they cannot, without another refraction, ever be brought to a focus. A convex lens by collecting these diverging rays can bring them to a focus.

Concave lenses are, in like manner, used to receive converging pencils of rays, and to restore them to their original direction ; thus these different lenses, in combination, are applied to most important uses, in the construction of optical instruments.

570. Of the *images formed by concave lenses.*

Fig. 222.



Let A B C be a concave lens. If the object E G F, be exposed to it, the rays G A, G C, G B, proceeding from the point G, will undergo a refraction, on leaving the glass, in the direction of A *l*, C *m*, and B *n*, as if they had issued from the point *g ;* and an eye placed behind the glass, at *m*, for example, will see the object just as if it were placed at *e g f*, and in a situation similar to that in which it is at the point G, but as many times smaller as the distance C G exceeds the distance G *g*. *Convex glasses* represent the image of a very distant object *behind them*, *concave glasses* represent it *before* them ; the *former represent it inverted*, and the *latter in its real situation ;* in both, the image is as many times smaller as the distance of the object from the glass, exceeds that of the glass from the image. On this property of glasses depends the utility of telescopes, spectacles, and microscopes.

Vision.

571. Who can estimate the value of sight, without which,

> " Day, or the sweet approach of ev'n or morn,
> Or sight of vernal bloom, or summer's rose,
> Or flocks, or herds, or human face divine,"

would " ne'er to us return." And even though we might see the objects immediately around us, and those above us in our own atmosphere, but could not extend our vision beyond these

570. How are objects represented by a concave lens ?
571. Advantages of sight.

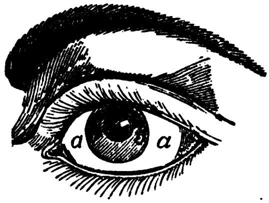
limits, of what sublime enjoyments should we be deprived! Confined as the soul is to a portion of matter which cannot soar beyond this terrestrial ball, if all beyond its atmosphere were dark and unfathomable, what a gloomy pall would hang over us! But we are permitted to contemplate the system of worlds of which ours forms a portion; and the splendors of God's creation are revealed to our wandering gaze. We learn the motions and laws which govern our own planet, by seeing and observing those of others. Our imaginations are awakened by the beauty and sublimity of the glorious firmament, and our hearts are warmed with love and admiration for Him who created this magnificent universe. How greatly then are *science*, *poetry* and *devotion*, indebted to the power of *distant* vision.

The Eye.

572. The eye, by turns a microscope and telescope, is adapted to the purpose of viewing things near, or of extending its field of vision to far distant objects. On examining the structure of the eye, we find it a beautiful *optical instrument* made in strict conformity to the laws of science, and perfectly fitted to be acted upon by light, so as to form an image of the object from which light is reflected. Was the Artist who formed this instrument ignorant of the effects to be produced? Or did the instrument itself blunder into existence, the offspring of chance or accident? We may not pursue these speculations; but cold must be the heart of him, who in studying these subjects, does not see something beyond the mere enunciation and illustration of scientific truths, and whose devout affections are not animated, as his understanding becomes enlightened!

573. The eye when viewed superficially, consists of the *white*, the *iris*, and *pupil*, but, by means of anatomical dissection, various other parts have been discovered.

Fig. 223.



"The figure exhibits a *front view* of the eye ball. The white part surrounding the center is called the *sclerotic** *coat a a*, and it is continued within the orbit, round the back part of the eye ball, being formed of a dense membrane, which includes, as in a bag, the other parts of the eye. It is perfectly opaque, and therefore is not continued over the front of the

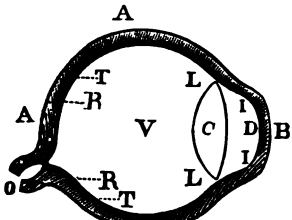
* From the Greek, *skleros*, hard.

572. The eye an optical instrument. Could not have been the result of accident.

573. Describe the eye as represented at Fig. 223.

eye, but joins the transparent *cornea*,* *b b*,, which differs from the sclerotic coat, in being completely pervious to light, and therefore serving like a window to admit light to the interior of the eye. Included within the cornea is the *iris*,† somewhat resembling a colored fringe, usually either of a dark brown, or a grayish blue tint; and hence the distinction between black, and blue, or gray eyes. In the center of the eye, surrounded by the iris, is a dark, circular space of variable dimensions, called the *pupil*, through which the rays of light pass into the chambers of the eye.

Fig. 224.



574. A *horizontal section* of the eye shows that it is enveloped in four membranes or coats; the sclerotic coat A A A; the cornea B, connected with tho former, in the front of the eye; the *choroid*‡ coat T T, which forms a lining to the sclerotic, and, on its opposite surface, is covered by a black pigment on which lies the interior coat of the eye, called the *retina*§ R R, a delicate net-work expanded over the inner chamber of the eye, and proceeding from the optic nerve, O, by which sensations are supposed to be conveyed to the brain. The interior of the eye, or the cavity surrounded by the coats just described, is filled by three substances called *humors:* The first, or the *aqueous humor*, D, is a fluid situated immediately behind the transparent cornea. The second, the *crystalline humor*, C, is directly behind the iris, being a solid, transparent lens, more convex behind than before; the third, called the *vitreous humor*, V, a kind of viscous, solid mass, contributing chiefly to preserve the globular figure of the eye. Between C and D is the *pupil* or opening in the iris, I I, through which light is admitted into the eye, and behind which the *crystalline humor* or lens is suspended in a transparent capsule, by the *ciliary processes*, L L, which proceed from the Iris.

575. We find, therefore, that the eye has *four coats* or membranes, viz.; the *sclerotic*, the *cornea*, the *choroid*, and the *retina*; *two humors*, viz; the *aqueous* and *vitreous*; and one *lens*, viz.; the *crystalline*.

* From the Latin *corneus*, horny, or like a horn.
† So called because it has many colors like the rainbow or *Iris*.
‡ From the Greek, *Korion*.
§ From the Latin, *rete*, a net.

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574. What does the interior of the eye present?
575. How many coats and humors has the eye? Situation of the eyes, use of muscles, eye-lids, &c.

The eyes are situated in basin-shaped cavities in the skull, called the *orbits*, and there are various *muscles* attached to the ball of the eye, and to different parts of each orbit, which, by their contraction, give a certain degree of lateral rolling motion to the eye, and thus assist in directing the sight towards particular objects, at pleasure. The *eye-lids*, also, moved by muscles and fringed by *eye-lashes*, serve to guard the eyes from dust, and to screen, or shut them altogether, from the access of too intense a light; and there are *glands* for the secretion of fluid to moisten the cornea, and, by the motion of the eye-lids, keep its surface clear, and in a state adapted to perfect vision.

LECTURE XXXV.

VISUAL ANGLE.—FORE-SHORTENING.—PERSPECTIVE.—INTENSITY OF LIGHT AND SHADE.—CONVERGENCE OF THE OPTIC AXES.

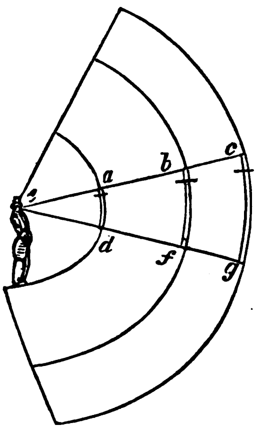
576. *The great purposes of vision are to distinguish the magnitude, figure, and distance of objects.* The means of effecting this are, 1st. *by the visual angle*, or the angle under which objects are seen; 2d. the *intensity of light, shade, and colors;* 3d. the *divergence of the rays of light, and the convergence of the optic axes.*

1. *The Visual Angle.*

577. The field of view is that open space around us, in which objects are seen. But the eye has not the power of taking in, at one view, the whole circle of the horizon. When a person stands with his face to the east, he cannot see the western horizon; nor can he, at one view, behold both the north and the south; because the range of human vision is less than half the circumference of the horizon. The scope of vision for the eye of man is not far from 45°, or one eighth of a circle. Within this range the distant landscape, with its numerous objects, may be depicted upon the retina of the eye. That is, a portion of the rays of light which diverge from objects in straight lines in all directions, falling upon the eye, are refracted by its transparent medium, and form a miniature picture upon the retina.

576. Objects of vision, and means by which they are perceived.
577. Field of view. Extent of the field of view.

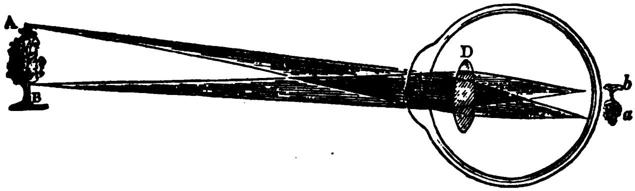
Fig. 225.



578. Suppose a person to be surrounded by a globe of glass, divided into equal degrees; he would, then, be able to know, exactly, what portion of his field of view was occupied, or intercepted, by any particular object, as the cross at *c;* and he would be able to judge of its relative size and situation. If the transparent globe were small as at *a d*, or larger as at *b f*, or *c g*, the part of its surface apparently occupied by any object beyond, or within it, would bear a similar proportion to the whole surface; thus, the cross at *a d* bears the same proportion to the small circle that *b f* and *c g* bear to the larger circles. Every circle being supposed to be divided into 360 degrees, (which degrees are, of course, smaller in a small circle, than in a larger one,) the magnitudes of objects are estimated, by observing how many of these degrees of the field of view each one occupies. The most convenient way of measuring a part of a circle of which the whole is not seen, is to measure the angle formed at its center, by lines drawn from the extremities of that part. In the figure, the angle at *e* being formed by the lines *c e* and *g e*, the object *c g* is said to occupy a certain number of degrees of the circumference of the circle, or to subtend an angle of a certain number of degrees at its center, which angle is called the *visual angle.* The objects at *b f* and *a d* subtend the same angle as the larger, but more distant object at *c g*. But the cross *c g*, which is about three times as large as *a d*, is also three times as far from the eye, and yet if no idea of their comparative distances entered into the computation of their magnitudes, the spectator, judging only from the visual angle, would suppose them to be of the same size.

579. Let A B represent a tree, with pencils of divergent rays issuing from the top and bottom. Entering the pupil of the eye, C, the rays are refracted by the crystalline lens, D, and form at

Fig. 226.



the retina, *a b*, an inverted picture of the tree. The nearer the tree is to the eye, the greater is the angle made by the meeting of the lines which proceed from the top and bottom.

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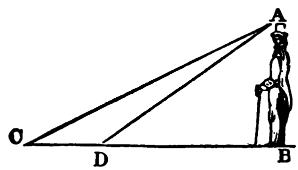
578. What is represented at Fig. 225? What is meant by the visual angle?
579. Tree seen at a distance. Man viewed at different distances.

Fig. 227.



Again, let A B represent a man viewed by an eye at C; the extreme rays proceeding from this object form the angle A C B. The angle at C is the visual angle. If the same object be viewed at the point D, the visual angle A D B will be greater. An object A B, seen at C, appears less than the same object seen at D, where the visual angle is greater; thus a tall man at a distance, may appear smaller than a child which is near. At four miles distance and without any interposing object, a man ceases to be visible.

580. "Astronomers measure very accurately the angles under which we see the heavenly bodies; and they have found that the visual angle of the sun is somewhat more than half a degree. If the sun were twice as far from us, this angle would be reduced to the half; and then it will not seem surprising that it should furnish us four times less light. And if the sun were 400 times further off, his visual angle would become so many times less, and then that luminary would appear no greater than a star. We must therefore carefully distinguish the *apparent* magnitude of any object from its *real* magnitude. The first is always an angle greater or less, according as the object is nearer or more distant. Thus the apparent magnitude of the sun is an angle of about half a degree, whereas his real magnitude far surpasses that of the earth; for the sun being a globe, his diameter is estimated to be about 790,000 English miles, while the diameter of the earth is only 7912 English miles."* If we should ask a child or an ignorant, unreflecting person, whether the moon is larger than a carriage-wheel, he would probably answer you in the negative. One better informed would tell you that the moon's distance when seen from the earth, greatly diminished its apparent size; and he would explain this phenomenon by showing that the apparent magnitude of objects depends upon the greater or less extent of the visual angle.

Vision requires the Aid of Experience.

581. The *real* magnitude and distance of objects is not determined by vision alone. We learn to judge of things unknown, by

* Euler.

580. Visual angle of the sun. Apparent and real magnitude of objects Apparent magnitude considered real.

581. Real magnitude not determined by vision alone. Doubts of Philosophers. Appearance of objects to a person who has suddenly received sight. *Learning* to see. Method by which painters give the effect of distance.

comparing them with such as are familiar. When we see a person whom we know, walking at a distance with a stranger, we judge of the height of the latter by comparison. The *visual angle* assists in forming a judgment as to the *distance* of an object when its real *magnitude* is known. When the *size* of a distant object is known, its *distance* may be determined; so on the other hand, when the *distance is known*, the *size may be ascertained* with sufficient accuracy.

Philosophers are in doubt as to the extent of knowledge of external things gained by sight, whether we are indebted to this sense for our knowledge of the *figure* and *magnitude* of bodies. An instance is related by the celebrated optician Chesselden, of his having, by means of a surgical operation, given sight to a man who was born blind.* "This person," it is said, "was at first dazzled; he could distinguish nothing as to the magnitude or distance of objects. All objects appeared so near that he wanted to handle them. And considerable time and long practice were requisite to bring him to the real use of sight. He was under the necessity of serving a long apprenticeship, such as we perform during the term of childhood, and of which we afterwards preserve no recollection. This apprenticeship it is, which instructed us, that an object appears to us so much the more clear and distinct as it is nearer; and reciprocally, that an object which appears clear and distinct is near; and when it appears obscure and indistinct, that it is at a distance. It is thus that painters, by weakening the tints of the objects which they wish to appear remote, and strengthening those which they would represent as nearer, are enabled to determine our judgment conformably to the effect which they mean to produce. And they succeed so perfectly, that we consider some of the objects represented in painting as more distant than others; an illusion which could not take place if vision discovered to us the real distance, and magnitude of objects."†

582. *Fore-shortening. The appearance of objects to the eye depends much on their position.* A *globe* always presents a circular image in whatever manner it may be viewed; but an *egg* may appear circular or oval, according to its position. A *wheel* when viewed in front, appears a perfect circle, when seen edgeways it appears like a broad straight band, and in other positions it appears oval. The sight of an object suggests the knowledge of its actual figure which we have gained by previous experience, and we think of its true figure rather than of the outline presented to the eye. Whoever attempts to draw from nature finds a difficulty

* The disease which occasioned the blindness referred to, is called a *cataract*, (from the Greek, *katarasso*, to confound or disturb.) It arises from the opacity of the crystalline lens, which is thus rendered unfit for its purpose of refracting light. By removing the lens out of the axis of vision, sight may be restored, if the retina is not diseased. This operation is called *couching*. In some cases the opaque crystalline lens is extracted. Glass lenses may be substituted for the lens of the eye for the purpose of collecting the rays of light.

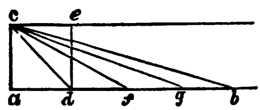
† Euler.

582. Apparent figure of objects depends on position. Effect of experience upon our judgment of things seen. Difficulty of drawing from nature.

in delineating objects as they appear. In drawing a row of trees of equal size, as they would appear to a person standing at one extremity, the nearer trees must be represented larger. If a stick of timber be placed with one end directly before the eye, and on a line parallel with it, that end, only, will be seen; if one of the sides be placed before the eye, the whole length will be seen; in any intermediate position, it will appear more or less shortened; the outline on the retina being similar to the shadow it would present on the wall, in the direction of the person viewing it.

583. Painters term the appearance of the surfaces or lines, when so placed as to face the spectator, *fore-shortening.* On looking abroad upon the extended surface, the distant portions are *fore-shortened* in proportion as they recede from the eye. Suppose a man standing on a plain at *c;* on looking down, he sees a portion of the surface with very little fore-shortening; an extent of five feet, as *a d*, (that is, allowing five feet to be the height of the eye) will subtend in the eye, an angle of 45°, *viz.* the angle *a c d;* or in other words, it will appear 45° in his field of view, in half of what is subtended by the whole space from his feet to the horizon; the next five feet will subtend the angle *d c f*, the next five feet the angle *f c g*, and the next five feet the angle *g c b*. Thus, as the man carries his view more and more forward, lines from the surface come to his eye more and more obliquely, until, at last, the light coming from the surface seems to be on a level with the eye. By understanding the effect of this fore-shortening, we partly judge of the distance and magnitude of the objects situated at various points of view.

Fig. 228.



Perspective.

584. The word perspective is from the Latin *per*, through, and *specio*, to look. The science of perspective teaches to draw on a *plane surface* true pictures of objects, as they appear to the eye, from any distance in an oblique position.

Suppose a straight view of the stone blocks or pillars (Fig. 229) extending from *a* to 8, to be viewed by a person standing near C; then, because objects appear smaller to the eye in exact proportion to their increased distance from it, the second block, if twice as far as the first, would appear only

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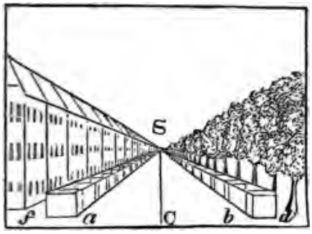
583. Meaning of the term fore-shortening. Effect of extending the view over a large surface.

584. What is perspective? Buildings, trees, and pillars seen in perspective. Vanishing point.

Fig. 229.



half as large; the third, if three times as far, would appear only one third as large, and so on to any extent, and for any other proportions; and if the 1,000th, or any other nearer or more distant pillar, subtended to the eye an angle less than the sixtieth of a degree of the field of view, it would be altogether invisible, even if nothing intervened between it and the eye. Where the row ceases to be visible from the minuteness of the parts, or from the fact of the nearer objects concealing the more remote, it may be said to have reached its *vanishing point*.

585. It is very remarkable that in any such case of a straight line, or row of trees or pillars vanishing from sight, in whatever direction it points, *east* for instance, although the eye to see the near end of it would have to look about north-east, still the point in the heavens, or in a picture, or transparent plane before the eye, where the line would vanish, would be exactly east from the eye, and not in the slightest degree either to the north or to the south of the east point, because the pillars happened to be north or south of the individual; and therefore, if there were two or more rows of pillars parallel to the first, but considerably apart from each other, as the lines *a* S, *b* S, *d* S, *c* S, and *f* S, still all would vanish, or seem to terminate in the very same point of the field of view. The reason of this is easily understood. Let us suppose a line drawn directly east from the eye, or to the point S, *viz.* a line directly over the line *b* S, and that the line of pillars *a* S, also pointing east, is 20 feet north of the spectator, and the line *b* S, running in the same direction, is 20 fe t south of him, then, evidently, for the same reason as the space between the top and bottom of the pillars, that is to say their height, becomes apparently less as their distance from the eye increases, so will the space between each pillar and the point corresponding to its place in the visual ray, or line along which the eye looks, become less, and the lines of pillars really 20 feet apart from the visual ray, will, at a certain distance from the eye, *viz.* where 20 feet is apparently reduced to a point, appear to join it, and the three lines will appear to meet in that point, beyond which they cannot be visible, and which is therefore called the *vanishing* point.

586. The conception of this truth may be facilitated by our supposing a star or planet to be rising in the eastern point of the heavens, at the moment of observation; then, if the three parallel lines were continued on to the planet, and were visible as far, they would arrive there with the 20 feet of interval between them just as they left the earth; but as any planet, although many thousand miles in diameter, owing to its distance from the earth, appears only a point, much more would the space between any two lines only 20 feet apart be there undistinguishable by human sight. And what is true of a space of 20 feet between parallel lines, is equally true, as regards human vision, of a space of hundreds of thousands of miles; as a general rule, therefore, it holds, that *all lines parallel to each other in perspective tend to and finish in the same vanishing point*, viz., the situation of the line in which the eye looks when directed parallel to any one of those real lines. And this is true not only of lines of the same level or horizontal plane, *viz.*, such as

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585. Explanation of the vanishing point in a picture.

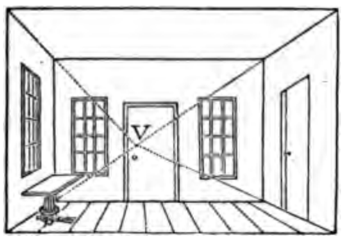
586. Suppose three parallel lines twenty feet apart to be continued to a planet or star. General rule in perspective with regard to parallel lines.

might be along the surface of the sea, but also of lines that are vertical or one above another, as those running along the tops and bottoms of the pillars, (Fig. 229,) or along the roofs and windows of the houses, and indeed of all lines in whatever situations, provided they are parallel to the visual ray.

587. When it is ascertained, therefore, that a line in any natural or artificial object, points 10 or 20 or any number of degrees north or south, or above or below the center of the scene or picture, that is to say, the *point of sight*, or principal visual ray, then also is it known that all the parallels to that line have their vanishing point in that spot of the field of view, and a line supposed to be drawn from the eye to the heavens, or really drawn to the picture in that direction, marks the *true vanishing point*.

It is explained now, why in a long arched tunnel, a bridge, or a cathedral with many longitudinal lines on its floor, walls, roof, &c., all such lines seen by an eye looking along from one end, appear to converge to a point at the other, like the radii of a spider's web; and why in the representation of a common room, viewed from one end, all the lines of the corners, tops and bottoms of windows, floors, stripes on the carpet, corners of tables, &c., being parallel to each other, tend to the same vanishing point as V, and are cut off by fore-shortening. The most important vanishing point in common scenes is the middle of the horizon, called by painters, the *horizontal line;* this in a picture, properly placed, is at the exact height of the eye. It is marked S in Fig. 229, and V in Fig. 230. Because in houses, the roofs, foundations, floors, windows, &c., are all horizontal, the vanishing points of their lines must be somewhere in the horizon; and if the spectator be in the middle of a street, or of a building, and be looking in the direction of its walls, their vanishing point will be in the center of the scene or picture; if he be elsewhere, it will be at one side. In holding up a picture frame, through which to view a scene suitable for a picture, it would be proper to raise it until the line of the horizon appeared to cross at about one third from the bottom;—this fact becomes the reason of the rule in painting, so to place the horizontal line. In beginning a picture, this line is usually the first line drawn on the canvass, as marking the place of the vanishing points of all level lines and surfaces. And the eye of the spectator is supposed to be placed in the middle of it, and generally about as far from the picture as the picture, itself, is long, such being the extent of view which the eye at one time most conveniently commands.

Fig. 230.



588. Dr. Arnott* justly remarks, that "much of the delight which the art of painting is calculated to afford, is lost to the world,

* The preceding remarks on Perspective are, with some variation, mostly taken from Arnott's "Elements of Physics."

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587. Method of ascertaining the vanishing point in a scene or picture. Why lines in a bridge, &c., when seen at one end seem to converge at the other. Horizontal line. The first line usually drawn on a picture. Manner in which a picture should be viewed.

588. Dr. Arnott's remarks about the proper manner of looking at a picture.

because persons, in general, know not how to look at a picture. Unless the spectator place himself where he can see the objects in true perspective, so that he may fancy himself looking at them through a window or opening, everything must appear to him false and distorted. The eye should be opposite the *point of sight* of the picture, and therefore on a level with the *horizontal line*, and it should be at the required distance, or about the length of the picture."

II. *Light and Shade, or the effects of color and distinctness of outline upon the appearance of objects in a landscape or picture.*

589. The apparent distance and magnitude of objects is affected by *distinctness of outline and brightness of color*; or *intensity of light and shade.*

The painter represents distant views by faint shades, and indistinct outlines. By deepening the shadows, or heightening the colors of a distant mountain, it seems at once brought nearer to the view, and the effect of distance is destroyed. Experience has thus taught us to associate the idea of distance, with faintness of coloring.

Light radiating from a center becomes rapidly weaker as the distance from this center increases. In looking upon a landscape illuminated by the sun, we see near objects, such as the flowers, fruit and foliage around us, distinct in outline, and glowing with bright hues. Strong lights and dark shadows prevail here. As the eye extends its range of vision, small objects are no longer visible; there is a blending of colors and of figure until at last the outline of the distant mountain or ocean fades away into the blue sky.

590. By the proper disposition of light and shade, and the management of colors combined with perspective, the painter is able to give a good representation of nature. Among the Chinese who are ignorant of perspective, pictures are figures of objects drawn on the same scale, and with a uniform vividness of coloring, whether the objects are supposed to be near or distant; their only way of representing distance, being to carry objects higher up the picture, as is done in the attempts at painting of children and untaught persons.

The art of fore-shortening in drawing, and of reducing the size of objects as they are more distant, is called *linear perspective.* The varying of color and the disposition of light and shade is called

589. Effect of light and shade.

590. How is the painter able to represent nature? Defect in Chinese pictures. Linear perspective.

aerial perspective. The knowledge of the effect of light and shade in painting is called *chiaro-oscuro.**

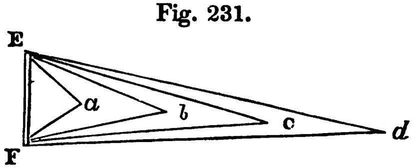
591. The effect of increased or diminished light in making objects appear near or remote, is obvious. When a fire breaks out in the night, it appears to a distant spectator, as if it were very near; and he often, for this reason, feels needlessly alarmed for the safety of his own dwelling. The bright, red glare reflected from surrounding objects brings them nearer to his eye, and he sees the firemen with their engines, and others running to and fro, in the bustle of the frightful scene, as if almost before his own door. The seaman beholding distant mountains suddenly illumined by a bright sun, deems himself near to the land. Again the sun is obscured, and the coast seems to have receded from him. Objects appear larger when seen through a foggy or misty atmosphere. This is owing to the diminished intensity of light which makes them appear more distant without diminishing the visual angle subtended by them; for to the man at forty rods distance, who subtends the same angle as the one at twenty rods distance, the same object must appear twice as large.

Thus, in the dim twilight, objects seem magnified: the illusion heightened by terror in the minds of the superstitious, readily converts a guide-board into a giant;—passing a church-yard in the night when the atmosphere is charged with vapors, fears may readily combine with the optical deception produced by such an atmosphere, and cause the white monuments to appear as colossal spectres, and the sapling willow with its pensile branches waving in the breeze, to seem like a huge monster tossing its arms to and fro. Many a ghost-story has arisen from appearances, which the ignorant, not understanding, have deemed supernatural. Strange lights which, as they supposed, warned them of some coming event, might, by a knowledge of the laws of optical reflection, have been traced to a candle at a neighboring window, or in the range of a mirror, which itself unseen, reflected light upon a wall.

III. *Divergence of the Rays of Light; and Convergence of the Optic Axes.*

592. Divergence of the rays of light assists in enabling us to judge of the distance or magnitude of objects. Suppose E F to be the pupil of the eye, and light entering it from an object at *a*. The rays spread with a large angle, or are more divergent than those from an object at *b*. At *c* and *d* the rays

Fig. 231.



* Italian words signifying *clear* and *obscure*, pronounced *kearo-scuro.*

591. Examples of the effect of increased or diminished light. A fire seen in the night. Distant mountains illuminated by a bright sun. Effects of a foggy atmosphere. Of twilight. Optical illusions.

592. Effect of divergence of light in enabling us to judge of distance. Painting cannot give this effect. Convergence of the optic axes. In what case greatest.

are still less divergent. In order to form an image on the retina, the eye must make an effort to bend, or refract the rays, exactly in proportion as they are divergent when they fall upon the crystalline lens; and the degree of effort thus made becomes a kind of measure of the distance and magnitude of the object. Painting cannot give this effect, for while in nature every object, according to its distance, is sending rays which meet the eye with different degrees of divergence, the rays from a picture coming from a single plane surface, have, in every part, the same divergence. The eye is not required to exercise the same effort of refracting the rays in accommodation to different distances; and this, in some measure, destroys the illusion that painting might otherwise cause.

By the *convergence of the optic axes*, we mean that the axis of each eye is directed towards one point, or that the two axes converge when both eyes are looking towards the same point. The optic axis is the axis of the crystalline lens continued to the object of vision. This *imaginary axis* back of the crystalline lens terminates at the *middle* of the retina, which is called the *point of distinct vision*. The inclination or convergence of the optic axes is greater for near objects than for distant ones.

Thus suppose E and F, (Fig. 231,) mark the places of the two eyes; if directed towards an object at *a*, it is evident that the two optical axes must have a greater convergence than if the eyes were directed towards *b*. When we look at very distant objects, the axes of the eyes seem parallel, and we cease to judge of distance by their convergence.

LECTURE XXXVI.

DURATION OF IMPRESSIONS UPON THE EYE.—SINGLE VISION.—IMPERFECTION OF VISION.—OPTICAL INSTRUMENTS.—SHADOW.

Duration of the Impression of Light upon the Eye.

593. If a stick burning at one end, is whirled by the hand, a circle of light is seen marking its path. As the burning end of the stick can only be in one point of the path in the same instant, it is manifest that the impression of its light continues on the eye after the object has left particular points from whence it was seen.

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593. Examples to prove that the impression of light upon the eye remains after the object which produced it is removed

It has been found that the light of a live coal, placed at the distance of 165 feet, continued its impression on the eye during the seventh part of a second.

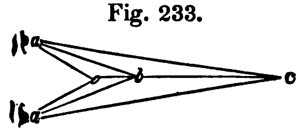
Fig. 232.

A toy called the *thaumatrope,** has been invented to illustrate this phenomenon. Fig. 232 represents a circular card, on one side of which there is drawn any object, as a carriage, and on the other, a man, in the attitude of driving. When the card, by means of strings affixed to it, is twirled round with some degree of velocity, the carriage and the driver appear as one picture. As one side must be out of sight while the other is towards us, it follows, that we see at once what is drawn upon both sides of the card, in consequence of the duration of the impression of light on the retina, when the object from which it proceeds is removed.

Cause of Single Vision with Two Eyes.

594. In consequence of the power of directing the axes of both eyes in one direction, or of the convergence of the optic axes, the mind sees but a single object, though an image is formed on each retina. This singleness of vision would take place if, instead of two, we had a much greater number of eyes; that is, supposing they could all direct their axes to the same point. By pressing one eye aside, when we are looking at any object, the axis is turned away from its line of inclination towards the axis of the other eye, and we see a double image. Images formed at the same time, of an object nearer to, or farther from the eye than the point where the axes meet, must appear double, because they are not formed at the point of distinct vision.

Fig. 233.



Supposing the point of distinct vision to be *a a*, in the center of the retina, and that the axes are directed towards the object at *b*, the image is seen single. But without changing the direction of the axes, attempt to look at an object beyond *b*, as at *c*, and the image on each eye will be formed outside the point of distinct vision, and will be seen double. On the contrary, attempt to look at an object at *o*, while the axes are directed towards *b*, and the image will be formed inside of the point of sight, and also appear double. A simple experiment will illustrate this. Hold the two fore fingers in a line from the eyes, so that one may be a little more distant than the other, by looking at the more distant the nearer will appear double, and by looking at the nearer, the more distant will appear double.

* From two Greek words signifying to *learn wonders.*

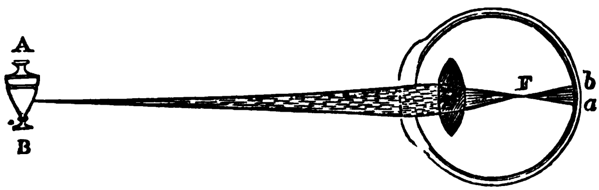
594. Why is it, that with two eyes, we see objects single? **Point of distinct vision.**

595. When the crystalline lens has ceased to be homogeneous, either from disease or age, small images, such as the letters of a book, will be seen double. Double vision is sometimes apparent in persons who are dying; it is also often occasioned by madness or intoxication. Many animals, as lizards, and fishes, and some birds, never see objects with more than one eye at a time. Some species of fish can only see such objects as are situated above them.

Imperfection of Vision.

596. When both eyes do not seem to be directed to the object at which a person is looking, he is said to be *squint-eyed. Short-sightedness* arises from too great a convexity of the crystalline lens, in which case, the rays of light are converged so much that they are brought to a focus before reaching the retina. Let D represent the crystalline lens, with pencils of light from A B falling upon it;

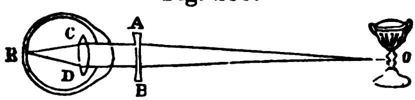
Fig. 234.



they are collected into a focus at F; from this point the rays proceed in a diverging manner, and form at the retina *a b*, a confused image. By bringing the object viewed *near to the eye*, as is done by short-sighted persons, the rays fall upon the eye more diverging, and are not so soon converged by the crystalline lens, so that the focus will fall upon the retina; for the nearer an object is brought to a lens, the farther the image recedes from it.

Short-sighted people are assisted by *concave lenses;* the effect of such lenses being to diverge rays of light. Thus the glass A B causes the rays which fall from the object *o*, to become more divergent; and the crystalline lens C D, which is too convex, then converges the rays, and the image or focus is thus thrown as far back as the re-

Fig. 235.

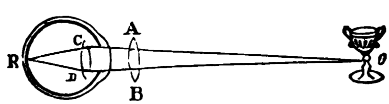


595. Different causes of double vision.
596. Squinting. Short-sightedness. Why do the short-sighted bring objects very near to the eye? Effect of concave lenses in assisting vision.

tina R. Without the aid of concave eye-glasses, near-sighted people cannot see objects at a little distance with any distinctness. As age advances, the eye becomes flatter, and this often enables those who were near-sighted in youth, to see without the aid of glasses of any kind.

597. *Long-sightedness* arises from a want of sufficient convexity in the crystalline lens. As age advances, the eye becomes flattened in consequence of the decay and shrinking of the refracting humors. This change is denoted by a tendency to hold a book at a greater distance when reading; for as the rays of light are not converged by the flattened crystalline lens sufficiently to bring them to a focus on the retina, this focus, or the image of the object is formed at a point beyond. A convex lens interposed between the object and the eye, by bending the rays to a greater convergence, brings the focus forward, and the image is formed on the retina. Thus the spectacles worn by aged persons are usually convex lenses. They do for the eye that portion of the labor of bending the rays of light, which it has not the ability to perform for itself. The functions of the eye being thus aided, the benefits of sight are secured to those who advance in years.

Fig. 236.



Let C D represent the crystalline lens of the eye, and A B a convex glass or *spectacle lens;* the object *o*, at about six inches from the eye, will form a perfect picture of the object at R, the retina. But if the lens A B be removed, the image will be confused, and it will be necessary to withdraw the eye to three or four times the distance, and if it be a minute object, the unassisted eye may not be able to distinguish it at any distance.

598. The *cataract* is a disease occasioned by the crystalline lens losing its transparency. This opacity, if total, prevents the passage of rays to the retina; if partial, it renders the image there formed, very dim and indistinct. The operation, or *couching*, for the cataract, consists in taking the defective lens or humor from the eye, in which case light can again revisit the "dim orb." But the principal converging power being gone, the image, instead of being formed on the retina, will be at a point beyond it. A convex, artificial lens here answers the purpose of the natural one. Thus persons who have undergone the operation of couching for the cataract, usually wear very convex spectacles.

Optical Instruments.

599. The ancients appear to have been better acquainted with

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597. Cause of long-sightedness. Indication of this defect. Effect of a convex lens where the eye is too flat.

598. Cataract and its remedy.

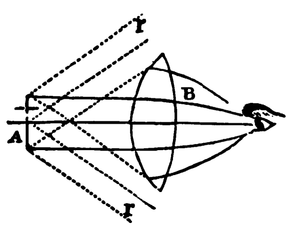
599. Optical glasses used by the ancients.

mirrors, or glasses for the reflection of light, than with lenses, or glasses for its refraction. The burning mirrors of Archimedes were named in history two hundred years before the Christian era.

600. *Spectacles* are lenses mounted upon a metallic frame so that they can be conveniently worn before the eyes. The spectacles worn by aged people are *convex* lenses; they assist the flattened, crystalline lens of the eye to converge the rays of light. The common eye-glasses carried by near-sighted people, are *concave* lenses, which counteract, by their divergence, the effect of too much roundness of the refracting lens of the eye. It is not ascertained by whom spectacles were invented; they were not in use before the thirteenth century, though the magnifying power of convex lenses was understood at an earlier period.

601. The *microscope** is designed to assist the eye *in viewing minute objects.*—A double convex lens, or small globe of glass, is the simplest kind of microscope. When applied to small objects, as the stamens or pericarp of a plant, the surface of a crystal, or the letters of a book, it exhibits parts not visible to the naked eye, or magnifies such as are visible. Without the aid of the microscope, we cannot view objects distinctly if held nearer to the eye than three or four inches. For when an object is brought nearer and nearer to the eye, we at length reach a point, within which, sight becomes confused. This point is called the *limit of distinct vision,* and varies a little in different persons. The cause of this confusion of sight is, that the divergence of the rays of light from a near object, is too great for the refracting power of the crystalline lens of the eye to collect them, to form an image on the retina.

Fig. 237.



If an object be placed within an inch or two of the eye, the rays which proceed from it are too divergent to be refracted so as to form a focus on the retina. But let the same object be viewed, at the same distance from the eye, by the assistance of the convex lens B, whose focal distance is B A; those rays diverging from the object which fall on the surface of the lens, will be refracted at its two surfaces, and

* From the Greek *micros*, minute, and *scopio*, to see.

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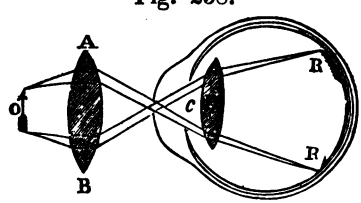
600. Spectacles. Eye-glasses.

601. Use of the microscope. Simplest kind of microscope. How does the microscope enable us to see objects nearer to the eye, than when the vision is unassisted? Why does the microscope magnify objects? Effect of looking upon the letters of a book through a pin-hole made in paper.

emerge from it nearly parallel to each other, consequently the object is capable of being viewed by the eye on the side B, under a greater angle than it could be seen without the lens. And, because the object is seen under a greater angle, it is magnified; and minute portions, which were before invisible because they did not occupy sufficient space on the retina, are now brought into view. Even by looking through a pin-hole in a piece of colored paper, the letters of a book will appear larger, and more distinct, than when seen in the ordinary way. This greater distinctness is owing to the exclusion of the *diverging* rays *r r*, of each pencil of light, which falling obliquely upon the eye, are not brought to the focus with the central rays, and therefore tend to confuse an image. The smallness of the pin-hole allows only the *axes* of the several rays to pass, and these proceed in lines almost parallel. Through such an aperture, letters appear very large and distinct, when a book is held within an inch of the eye. On removing the perforated paper, and attempting to look at the letters at the same distance as before, there is no distinct vision.

602. The *single microscope* consists of a convex glass called a magnifying glass, in the focus of which, is the object. By means of the converging power of the magnifier, the eye may be brought very near the object. The rays from the object at O being bent at A B, proceed to the pupil C, and fall on the crystalline lens, D, in such a manner, as, when again refracted, they form a magnified image on the retina R R. The more convex a lens is, the shorter is its focus; and the shorter the focus of a lens, the greater is its magnifying power.

Fig. 238.



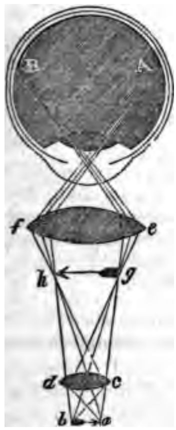
603. It is important, for many purposes, to know the exact magnifying power of a microscope; that is, whether it makes an object appear ten, fifty, or a hundred times larger, than when viewed with the naked eye. This magnifying power depends on *the difference of the distance of the object from a lens*, and the distance when seen without its assistance; or, in other words, *on the ratio between the focal distance of the lens, and the limits of distinct vision.* This latter point varies in different persons, and at different periods of life in the same person. In reading, the most common distance at which we hold a book from the eyes, is, proba-

602. Single microscope.

603. On what the magnifying power of a microscope depends. Focus of the eye, or points of distinct vision.

bly about ten inches. When we examine the different parts of a flower or an insect, we hold the object nearer.

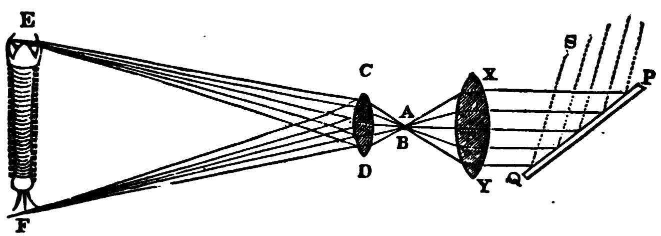
Fig. 239.



604. The *compound microscope* consists of two, or more, convex lenses, one of which, called the *object-glass*, is used to form an enlarged image of the *object*, and the other, called the *eye-glass*, to magnify the *image*. In the single microscope the magnified object is seen; in the compound microscope the object is not seen, but its magnified image. Suppose an object *a b*, to be placed a little beyond the focus of the *object-glass* *c d*, the rays of light proceeding from it will be collected on the other side of the lens and form an enlarged and inverted image at *g h*. The *eye-glass* *e f*, again magnifies the image which is formed on the retina at A B, in an upright position.

605. The *solar microscope* is so named, because the object is illuminated by the solar light, reflected from a plane mirror. It has two lenses contained within a tube which, when the microscope is used, is placed in a hole in the window-shutter of a darkened room. The reflector is placed outside the shutter, to receive the solar rays; these fall upon a large convex lens called a *condenser*, whose office is to collect the rays, and throw them upon an object placed within its focus. These rays are again refracted, and form behind the second lens, a magnified image of the object which is thrown upon a screen. Let P Q represent the reflector of a solar microscope S, incident rays which

Fig. 240.



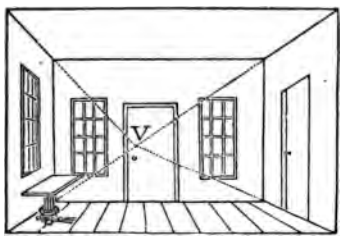
604. Parts of the compound microscope. Explain the manner in which objects are viewed through a compound microscope.
605. Solar microscope. Explain the manner in which the solar microscope is used. Discoveries made by means of the solar microscope.

might be along the surface of the sea, but also of lines that are vertical or one above another, as those running along the tops and bottoms of the pillars, (Fig. 229,) or along the roofs and windows of the houses, and indeed of all lines in whatever situations, provided they are parallel to the visual ray.

587. When it is ascertained, therefore, that a line in any natural or artificial object, points 10 or 20 or any number of degrees north or south, or above or below the center of the scene or picture, that is to say, the *point of sight*, or principal visual ray, then also is it known that all the parallels to that line have their vanishing point in that spot of the field of view, and a line supposed to be drawn from the eye to the heavens, or really drawn to the picture in that direction, marks the *true vanishing point*.

It is explained now, why in a long arched tunnel, a bridge, or a cathedral with many longitudinal lines on its floor, walls, roof, &c., all such lines seen by an eye looking along from one end, appear to converge to a point at the other, like the radii of a spider's web; and why in the representation of a common room, viewed from one end, all the lines of the corners, tops and bottoms of windows, floors, stripes on the carpet, corners of tables, &c., being parallel to each other, tend to the same vanishing point as V, and are cut off by fore-shortening. The most important vanishing point in common scenes is the middle of the horizon, called by painters, the *horizontal line;* this in a picture, properly placed, is at the exact height of the eye. It is marked S in Fig. 229, and V in Fig. 230. Because in houses, the roofs, foundations, floors, windows, &c., are all horizontal, the vanishing points of their lines must be somewhere in the horizon; and if the spectator be in the middle of a street, or of a building, and be looking in the direction of its walls, their vanishing point will be in the center of the scene or picture; if he be elsewhere, it will be at one side. In holding up a picture frame, through which to view a scene suitable for a picture, it would be proper to raise it until the line of the horizon appeared to cross at about one third from the bottom;—this fact becomes the reason of the rule in painting, so to place the horizontal line. In beginning a picture, this line is usually the first line drawn on the canvass, as marking the place of the vanishing points of all level lines and surfaces. And the eye of the spectator is supposed to be placed in the middle of it, and generally about as far from the picture as the picture, itself, is long, such being the extent of view which the eye at one time most conveniently commands.

Fig. 230.



588. Dr. Arnott* justly remarks, that "much of the delight which the art of painting is calculated to afford, is lost to the world,

* The preceding remarks on Perspective are, with some variation, mostly taken from Arnott's "Elements of Physics."

587. Method of ascertaining the vanishing point in a scene or picture. Why lines in a bridge, &c., when seen at one end seem to converge at the other. Horizontal line. The first line usually drawn on a picture. Manner in which a picture should be viewed.

588. Dr. Arnott's remarks about the proper manner of looking at a picture.

because persons, in general, know not how to look at a picture. Unless the spectator place himself where he can see the objects in true perspective, so that he may fancy himself looking at them through a window or opening, everything must appear to him false and distorted. The eye should be opposite the *point of sight* of the picture, and therefore on a level with the *horizontal line*, and it should be at the required distance, or about the length of the picture."

II. *Light and Shade, or the effects of color and distinctness of outline upon the appearance of objects in a landscape or picture.*

589. The apparent distance and magnitude of objects is affected by *distinctness of outline and brightness of color;* or *intensity of light and shade.*

The painter represents distant views by faint shades, and indistinct outlines. By deepening the shadows, or heightening the colors of a distant mountain, it seems at once brought nearer to the view, and the effect of distance is destroyed. Experience has thus taught us to associate the idea of distance, with faintness of coloring.

Light radiating from a center becomes rapidly weaker as the distance from this center increases. In looking upon a landscape illuminated by the sun, we see near objects, such as the flowers, fruit and foliage around us, distinct in outline, and glowing with bright hues. Strong lights and dark shadows prevail here. As the eye extends its range of vision, small objects are no longer visible; there is a blending of colors and of figure until at last the outline of the distant mountain or ocean fades away into the blue sky.

590. By the proper disposition of light and shade, and the management of colors combined with perspective, the painter is able to give a good representation of nature. Among the Chinese who are ignorant of perspective, pictures are figures of objects drawn on the same scale, and with a uniform vividness of coloring, whether the objects are supposed to be near or distant; their only way of representing distance, being to carry objects higher up the picture, as is done in the attempts at painting of children and untaught persons.

The art of fore-shortening in drawing, and of reducing the size of objects as they are more distant, is called *linear perspective.* The varying of color and the disposition of light and shade is called

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589. Effect of light and shade.

590. How is the painter able to represent nature? Defect in Chinese pictures. Linear perspective.

aerial perspective. The knowledge of the effect of light and shade in painting is called *chiaro-oscuro.**

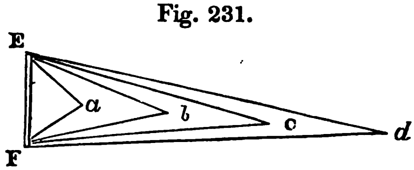
591. The effect of increased or diminished light in making objects appear near or remote, is obvious. When a fire breaks out in the night, it appears to a distant spectator, as if it were very near; and he often, for this reason, feels needlessly alarmed for the safety of his own dwelling. The bright, red glare reflected from surrounding objects brings them nearer to his eye, and he sees the firemen with their engines, and others running to and fro, in the bustle of the frightful scene, as if almost before his own door. The seaman beholding distant mountains suddenly illumined by a bright sun, deems himself near to the land. Again the sun is obscured, and the coast seems to have receded from him. Objects appear larger when seen through a foggy or misty atmosphere. This is owing to the diminished intensity of light which makes them appear more distant without diminishing the visual angle subtended by them; for to the man at forty rods distance, who subtends the same angle as the one at twenty rods distance, the same object must appear twice as large.

Thus, in the dim twilight, objects seem magnified: the illusion heightened by terror in the minds of the superstitious, readily converts a guide-board into a giant;—passing a church-yard in the night when the atmosphere is charged with vapors, fears may readily combine with the optical deception produced by such an atmosphere, and cause the white monuments to appear as colossal spectres, and the sapling willow with its pensile branches waving in the breeze, to seem like a huge monster tossing its arms to and fro. Many a ghost-story has arisen from appearances, which the ignorant, not understanding, have deemed supernatural. Strange lights which, as they supposed, warned them of some coming event, might, by a knowledge of the laws of optical reflection, have been traced to a candle at a neighboring window, or in the range of a mirror, which itself unseen, reflected light upon a wall.

III. *Divergence of the Rays of Light; and Convergence of the Optic Axes.*

592. Divergence of the rays of light assists in enabling us to judge of the distance or magnitude of objects. Suppose E F to be the pupil of the eye, and light entering it from an object at *a*. The rays spread with a large angle, or are more divergent than those from an object at *b*. At *c* and *d* the rays

Fig. 231.



* Italian words signifying *clear* and *obscure*, pronounced *kearo-scuro.*

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591. Examples of the effect of increased or diminished light. A fire seen in the night. Distant mountains illuminated by a bright sun. Effects of a foggy atmosphere. Of twilight. Optical illusions.

592. Effect of divergence of light in enabling us to judge of distance. Painting cannot give this effect. Convergence of the optic axes. In what case greatest.

are still less divergent. In order to form an image on the retina, the eye must make an effort to bend, or refract the rays, exactly in proportion as they are divergent when they fall upon the crystalline lens; and the degree of effort thus made becomes a kind of measure of the distance and magnitude of the object. Painting cannot give this effect, for while in nature every object, according to its distance, is sending rays which meet the eye with different degrees of divergence, the rays from a picture coming from a single plane surface, have, in every part, the same divergence. The eye is not required to exercise the same effort of refracting the rays in accommodation to different distances; and this, in some measure, destroys the illusion that painting might otherwise cause.

By the *convergence of the optic axes*, we mean that the axis of each eye is directed towards one point, or that the two axes converge when both eyes are looking towards the same point. The optic axis is the axis of the crystalline lens continued to the object of vision. This *imaginary axis* back of the crystalline lens terminates at the *middle* of the retina, which is called the *point of distinct vision*. The inclination or convergence of the optic axes is greater for near objects than for distant ones.

Thus suppose E and F, (Fig. 231,) mark the places of the two eyes; if directed towards an object at *a*, it is evident that the two optical axes must have a greater convergence than if the eyes were directed towards *b*. When we look at very distant objects, the axes of the eyes seem parallel, and we cease to judge of distance by their convergence.

LECTURE XXXVI.

DURATION OF IMPRESSIONS UPON THE EYE.—SINGLE VISION.—IMPERFECTION OF VISION.—OPTICAL INSTRUMENTS.—SHADOW.

Duration of the Impression of Light upon the Eye.

593. If a stick burning at one end, is whirled by the hand, a circle of light is seen marking its path. As the burning end of the stick can only be in one point of the path in the same instant, it is manifest that the impression of its light continues on the eye after the object has left particular points from whence it was seen.

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593. Examples to prove that the impression of light upon the eye remains after the object which produced it is removed

Fig. 246.

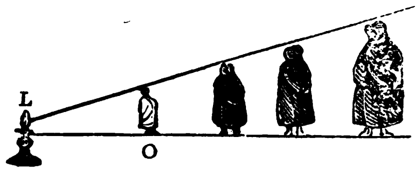


Fig. 247.

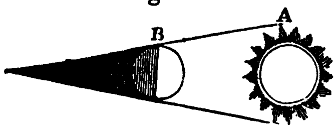
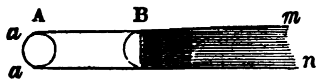


Fig. 248.



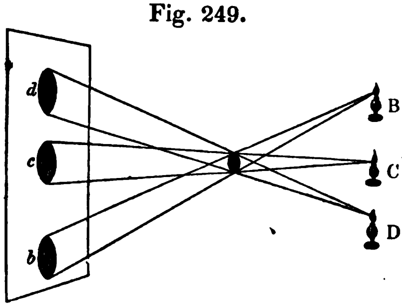
than the opaque body. Let L be a luminous body, smaller than the opaque body O. It is evident from the diverging of the rays, that the shadow will be larger in proportion to its distance from the object.

2d. *When the luminous body is larger than the opaque body.* Thus let A be a luminous body, (the sun) and B an opposite body, (the earth,) the shadow will be in the form of a cone, and will gradually diminish in size till it terminates in a point.

3d. *When the luminous body is of the same magnitude as the opaque body.* Here the shadow will be that of a cylinder. Thus let A be a luminous body of the same magnitude as B. The lines *a m* and *a n* are parallel, and if the shadow of B were extended to infinity, it would be cylindrical.

614. The darkness of a shadow is in proportion to the intensity of light which is interrupted by the opaque body. Though as surrounding objects reflect light, the shadow itself will be in some measure illuminated. Were it not for this, shadows would appear perfectly black.

Fig. 249.



A number of lights will cause the same number of shadows of the same object, unless the lights are situated in the same line of direction. Suppose a ball A, to receive light from three lamps, B C and D; the light B will produce the shadow *b*, the light C will produce the shadow *c*, and the light D the shadow *d*, but the shadows will not be very dark, because they

614. Cause of the different degrees of darkness in shadows. Cause of several shadows of the same object.

receive some light from the two lamps which are out of their line of direction. The ball hides the light from the lamp C; but the wall at the place of the shadow *c* is illuminated by the other two lamps.

LECTURE XXXVII.

NATURE OF LIGHT.—DECOMPOSITION OF LIGHT.—DISPERSION OF LIGHT.—RAIN-BOW.—ABSORPTION OF LIGHT.

615. The *colorless* light which proceeds from the sun, is *reflected in a variety of colors* from the foliage of trees, the petals of flowers, and other innumerable objects around us. How beautiful, how kind, and how wise is this arrangement! A clear transparent light meets our gaze when we look upwards or around us in space; but when we look down upon the earth, our eyes are feasted by the brilliant and delicate hues which issue from this transparent light, as it is decomposed by the objects on which it falls.

Theories respecting the Nature of Light.

616. There has ever been much dispute respecting the nature of light. The ancients asserted that there *must be something* between the eye and the object seen; for, without *some medium* there could be no communication. The great question was to ascertain what this medium, or *this something* was. One supposed "that the eyes, themselves, emit rays, or emanations of some unknown kind, by which distant objects are, as it were, felt." This hypothesis was absurd, because it assigned no reason why objects should not be seen as well in the dark as light, or in fact why there should be any darkness at all. Others imagined "that all visible objects are constantly throwing off in all directions, images, films, or spectral resemblances of themselves, which produce our impressions of the objects." Aristotle, in accordance with this opinion, supposed the mind to reside in the brain, which was filled with the images, or *forms of ideas as well as things.*

617. Newton, the great founder of the science of optics, rejecting this idea of *spectra*, or resemblances being thrown off by the luminous body, supposed that particles of incalculable minuteness, dart, in all directions, from every portion of the surface of luminous bodies; and that these particles are subjected to the laws of attraction and repulsion. Attributing to light these properties of matter, he believed light, itself, to be material, and that its particles were turned aside so as never to come in actual contact with the particles of the bodies

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615. Reflection the cause of colors.

616. Opinions of the ancients respecting the nature of light. Aristotle's opinion.

617. Newton's theory.

on which they fall; but either being turned back and *reflected* by the repulsive forces before they meet them, as in the case of opaque bodies, "or penetrating between their intervals, as a bird may be supposed to fly through the branches of a forest and undergoing all their actions, to take, at quitting them, a direction according to the position of the surface at which they emerge with respect to their course."* Newton's theory is called the *system of emanation*, it being imagined that rays of light emanate from the sun, as water issues from a fountain.

618. Another theory with respect to the nature of light seems, at the present day, to be in favor with many eminent writers. This supposes "light to be produced in the same manner as sound, by the communication of a *vibratory motion* from the luminous body to a highly elastic fluid," called *ether*, which fills all space. Thus instead of anything being actually thrown off, this theory supposes light to depend on vibrations or undulations of ether, caused by that luminous body, as sound depends on pulsations of air produced by the sonorous body.

There are strong objections to this theory. In the first place, it *supposes* a substance, (ether,) which *we do not know* to exist; and it is contrary to the rules of sound philosophy, thus to refer to a cause of which we have no knowledge; and secondly, its explanations of various phenomena of light are neither so simple nor so satisfactory as by the Newtonian theory. Still there are analogies so close between sound and light, that there is some plausibility in referring them to analogous causes.

619. One of the great advocates for the theory of vibrations, Euler, after asserting the existence of a subtle medium which pervades all space, says, "As the vibrations of air produce sound, the vibrations of ether produce light. The rays of light consist in the shapes and vibrations transmitted by the ether, as sound consists in the shakings or vibrations transmitted by the air. The sun then loses nothing of his substance† in this case, any more than a bell does in

* The learned Sir John Herschell, who is not a disciple of the Newtonian school, in respect to the nature of light, thus humorously illustrates Newton's doctrine of refraction; but truth *may* be uttered in jest, and those who believe in the system of emanation, may thank Sir John for his apt and *lively* simile.

† The fears which some Philosophers seem to entertain lest the sun will, in process of time, part with all its light, seems to show but little confidence in the providence of Him who spake light into existence;—why do we not fear lest the fountain of rivers will be dried, or lest the northern and southern portions of the globe will be left without an atmosphere, since the air is continually rushing from thence towards the equator? We know that God has provided means for a constant renewal of the fountains by evaporation, and that there are in the upper regions of the atmosphere supplies of air going to restore the equilibrium. Thus the sun which bestows light upon all bodies within its system, may in return, by some process analogous to evaporation, draw from the opaque planets of its system, the elements of which light is composed, (for it is evident that light is a chemical combination of various elements.) Everywhere in nature we perceive a system of *compensations*; the plant yields to the animal the vital element, and the animal in breathing sends forth the substance which alone can give life and vigor to the plant. Shall we say, *we do not understand* how God can replenish the *lamp* he has set in the heavens, and therefore we will not believe his own assertion, "that he gave the sun to rule the day?" but the rather admit that every object which *seems to reflect light* is in motion, and that light, itself, is nothing but undulations of a supposed medium which all these vibrating objects put into motion. Instead of the sublime passage, "God said let there be light, and there was light," we should read, "and God said, let everything begin to vibrate, so that there may be an *appearance* of light." But we are met by another difficulty;—at the period when the scriptures inform us light was created, there had been nothing else formed, and therefore there could be no vibratory bodies.

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618. Theory of vibrations. Objections to this theory.

619. Euler's remarks with respect to light and sound. Comments of Euler upon Newton's theory of light. Opaque bodies compared to musical instruments. Colors accounted for on the system of vibrations. Leading doctrines of optics firmly established.

Fig. 250.

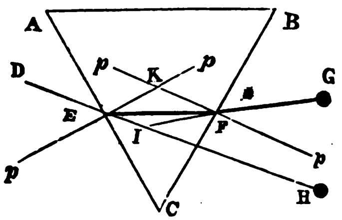
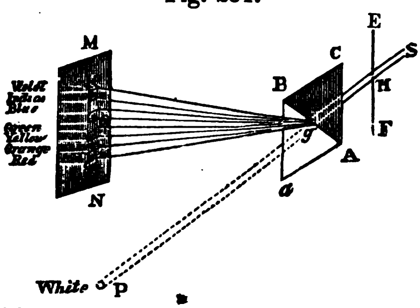


Fig. 250 represents a section of a prism ABC, of which AB is the *base*, and ACB the *refracting angle*. DE is a beam of the sun's light falling obliquely on the first surface AC, where one portion is reflected but another portion transmitted.—The latter portion, instead of passing directly forward and forming an image of the sun at H, is turned upward towards the perpendicular *p p*, meeting the opposite surface CB in F, where it is again turned upward from the perpendicular *p p* in the direction FG, carrying the image of the sun from H to G."*

621. By means of the prism, Newton proved that light consists of seven different kinds of rays, varying in color, refrangibility, and other properties. Let a room be darkened, and admit a beam of light obliquely through a hole in the window shutter. If this beam of light be received upon a screen,† or upon the wall, a luminous spot only will appear; but if a lens be placed before the beam of light, the rays will be bent out of their straight forward course, and, in this refraction, they will separate and arrange themselves in the screen, according to their different degrees of refrangibility.

Fig. 251.



E F represents the window shutter, H a hole in the same, S the beam of light, which, if not interrupted, would go on, in a straight line, and form a round white spot at P.—B A C is a prism, whose refracting angle is at A. The beam of light falling on its first surface, C A, emerges at an equal angle of refraction from its second surface, B A, in the direction *g* G. From the ordinary examples of refraction, we should expect that this beam of light, which before fell upon P, would only change its direction, and fall somewhere upon M N. But instead of a round, white spot, there appears on the screen M N, an oblong image K, divided into seven, colored spaces, of unequal extent, and arranged in the order represented, beginning with the red.

* Olmsted.

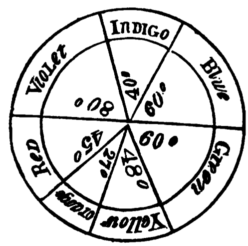
† A piece of white paper or the white wall will serve the purpose of a screen, but a sheet of drawing paper fixed to a movable stand is the most convenient.

621. Experiments with the prism colors exhibited in the solar or prismatic *spectrum*.

This image is called the *solar*, or *prismatic spectrum*. It will be seen that the red ray is nearest the line P H, in which the light would have proceeded if it had suffered no refraction, while the violet is the most distant, from this line; therefore the *red* ray is the *least refrangible*, and the *violet* ray the *most refrangible*.

622. The various colored rays of the spectrum may be collected by a convex lens, and when the image is received on a screen, a circular spot of white light is produced. Thus by *synthesis*, as well as analysis, is proved the compound nature of lights. That the seven colors of the spectrum produce white light may also be proved by the following experiment. On a circular card, paint the colors in their due proportions; on turning the card rapidly, the colored circle will appear white. It will be seen by the figure that the width of the violet ray is the greatest, being 80°, and that of the orange the least, being 27°; green and blue occupy each 60° of the spectrum, yellow 48°, red 45,° and indigo 40°.

Fig. 252.



623. *Homogeneous Light.* It is asserted by some modern writers that there are but *three homogeneous or simple colors, viz.;* red, yellow and blue. Orange may be made by mixing red and yellow; green, by mixing yellow and blue; and violet a faint shade of indigo, mixed with a little red.

Sir David Brewster, one of the most popular writers on optics, of the present day, thus remarks upon homogeneous light. "Among the wonders of science, there are perhaps none more surprising than the effects produced upon colored objects by illuminating them with homogeneous light, or light of one color." After describing the method by which, owing to late chemical discoveries, yellow light may be produced in sufficient quantities for illuminating a room, he continues: "Having thus obtained the means of illuminating any apartment with yellow light, let the exhibition be made in a room with furniture of various bright colors, with oil or water colored paintings, on the wall. The party which is to witness the experiment should be dressed in a diversity of the gayest colors; and the brightest colored flowers and highly colored drawings should be placed on the tables. The room being first lighted with ordinary lights, the bright and gay colors of everything that it contains will be finely displayed. If the white lights are now suddenly extinguished, and the yellow lamps lighted, the most appalling metamorphoses will be exhibited. The astonished individuals will no longer be able to recognize each other. All the furniture in the room, and all the objects which it contains, will exhibit only one color. The flowers will lose their hues. The paintings and drawings will appear as if they were executed in Chinese ink, and the gayest dresses, the brightest scarlets, the purest lilacs, the richest blues, and the most vivid greens, will all be converted into one mo-

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622. White light produced by collecting the prismatic colors.

623. Remarks of Brewster upon homogeneous light. Effects of illuminating objects with homogeneous light. Effect of illuminating v
colored light.

notonous yellow. The complexions of the parties, too, will suffer a corresponding change. One pallid death-like yellow,

——like the unnatural hue
Which autumn plants upon the perished leaf,

will envelop the young and old, and the sallow faces will alone escape from the metamorphosis. Each individual derives merriment from the cadaverous appearance of his neighbor, without being sensible that he is himself one of the ghostly assemblage.

If, in the midst of the astonishment which is thus created, the white lights are restored at one end of the room, while the yellow lights are taken to the other end, one side of the dress of every person, namely, that next the white light, will be restored to its original colors, while the other side will retain its yellow hue One cheek will appear in a state of health and color, while the other retains the paleness of death, and, as the individuals change their position, they will exhibit the most extraordinary transformations of color.

If, when all the lights are yellow, beams of white light are transmitted through a number of holes like those in a sieve, each luminous spot will restore the color of the dress or furniture upon which it falls, and the nankeen family will appear all mottled over with every variety of tint.

If red and blue light could be produced with the same facility, and in the same abundance as yellow light, the illumination of the apartment with these lights in succession would add to the variety and wonder of the exhibition. The red light might perhaps be procured in sufficient quantity from the nitrate and other salts of strontia; but it would be difficult to obtain a blue flame of sufficient intensity for the suitable illumination of a large room. Brilliant white light, however, might be used, having for screens glass troughs containing a mass one or two inches thick of a solution of the ammoniacal carbonate of copper. This solution absorbs all the rays of the spectrum but the blue, and the intensity of the blue light thus produced would increase in the same proportion as the white light employed."

624. *Dispersion of Light.* It is found that the length of the solar spectrum depends on the nature of the prism employed, by experiments made with transparent liquid substances of various kinds, inclosed within glass plates arranged in a triangular form. The *oil of cassia*, when used as the material for a prism, forms a spectrum twice as long as the common glass prism; it is, therefore, said to have a *greater dispersive power* than glass.

625. The difference between *dispersion* and *refraction* is very important. Newton did not observe that the dispersion or divergence of the different colors on the spectrum was greater when produced by one refracting body, than by another. He therefore, erroneously concluded, that the refractive and dispersive powers of bodies must always correspond. In the construction of his refracting telescopes he found much difficulty from the colored fringes which rendered the image indistinct. Opticians have now learned to correct this defect, by the use of lenses of different dispersive powers. Telescopes constructed thus are called *achromatic.** The eye is an achromatic instrument. Its crystalline, aqueous, and vitreous humors, form lenses

* From the Greek, *a*, destitute of, and *kroma*, color.

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624. What is meant by the dispersing power of any reflecting substance?
625. Error of Newton with respect to dispersion and refraction. Defects of Newton's telescopes. How remedied.

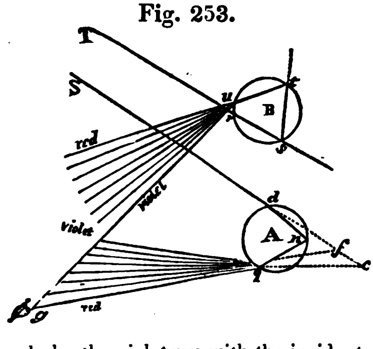
possessing different dispersive powers, which mutually correct the aberrations of each other.

626. *Rain-bow.* The rain-bow shows the prismatic spectrum on a grand scale,

> "Bestriding earth the grand etherial bow
> Shoots up immense; and every hue unfolds,
> In fair proportion, running from the red
> To where the violet fades into the sky."

The rain-bow is caused by the *reflection* and *refraction* of light by means of drops of water, which produce the effects, both of convex mirrors, and convex lenses. It is when the sun may be seen shining through falling rain-drops that we see the rain-bow. If drops of rain were *flat*, instead of being round, the rays of light would be reflected by them to the earth without being divided into prismatic colors, and the rain-bow would appear an arch of glittering, colorless light. But the *spherical* drops first bend, or refract the rays, dispersing prismatic colors, and then reflect them in the varied colors, and in the order they are exhibited in the prism.

Fig. 253.



Suppose A to be a drop of rain, and S *d* a ray of light falling upon it at *d*; it will not go to *c*, but be refracted to *n*, here one part will leave the drop, and another part be reflected to *q*, where it will suffer a second refraction; the drop acting as a prism, separates (*disperses*) the ray into the colors of the spectrum, the red being lowest, and the violet highest, or, in other words, the red being least refracted, and the violet most refracted. The angle made by the red ray with the solar, incident ray, that is, the angle S *f q*, is about 42 degrees, while that made by the violet ray with the incident ray, or the angle S *c q*, is about 40 degrees. It is in this way that the *primary* or principal rain-bow is formed by the united effect of innumerable rain-drops, each suffering two refractions of light, and one reflection.

627. There are often seen two bows, the one above the other, fainter, and with the colors in a reversed order. This is called the *secondary rain-bow.* The rays do not reach the eye of the spectator, until after *two reflections* and *two refractions.*

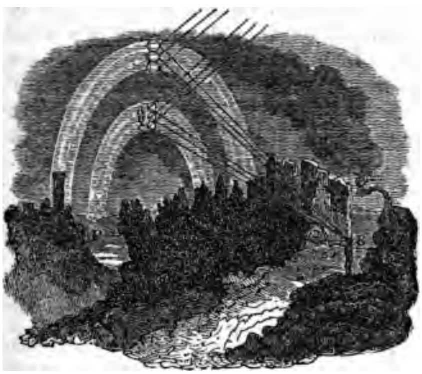
Thus suppose the ray T *r* (see Fig. 253,) enters the drop B, at *r*, where it is refracted, at *s* it is reflected to *t*, and again reflected to *u*, where it is a

626. Cause of the rain-bow. Explanation of the rain-bow.

627. The secondary rain-bow. Cause of the arched appearance of the rain-bow.

second time refracted, and passes on towards g. The red ray is still nearest the inverted ray T r, and the violet ray is the most distant. But a spectator at g would see the spectrum reversed in the secondary rain-bow. This is because the light enters at the lower part of the drop, and is transmitted through the upper part. The secondary bow is also fainter, in consequence of the light which is lost by two reflections.

Fig. 254.



The arched appearance of the rain-bow is owing to the refracted rays being visible to our eyes, only at certain angles. Thus, if a line be drawn horizontally, from the eye of the spectator, as E P, it is evident that angles formed with this line of a certain dimension in every direction, will produce a circle. Suppose three drops of rain only to be represented in the primary rain-bow, it will appear that the angle C E P is less than the angle B E P, and that the angle A E P is the greatest of the three. This larger angle is formed by the red rays, the middle one by the green, which is also the middle of the spectrum, and the smallest by the violet or extreme ray.

628. *Absorption of Light.* The most transparent bodies in nature, as air and water, when in sufficient thickness, are capable of absorbing a great quantity of light. On the summits of high mountains, where light passes through a less thickness of atmosphere, more stars are visible than in the plains below. On looking up through a considerable depth of water, luminous objects are scarcely visible. The red color of the morning and evening clouds is owing to the absorption of the colored rays by the air; and the noon-day sun when viewed from a diving-bell, in the depths of the sea, appears of the same hue. It is supposed that the light absorbed is *stopped* by the particles of the absorbing body, and remains within it, in the form of impenetrable matter.* All the light that is not either *absorbed* or *transmitted* is reflected, and the body *assumes the color of the reflected ray.*

629. There is reason for believing that there are certain rays of solar light which never reach our globe. When a prism is very

* Brewster's Optics.

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628. Effects of the absorption of light. Is the color of a body owing to light which is absorbed or reflected?

629. Black lines in the solar spectrum; how accounted for?

perfect, and the sun-beam is received on a white sheet of paper, it presents the appearance of a ribbon shaded with all the prismatic colors, having its breadth irregularly striped by a number of *black lines*. These rayless lines are so narrow that they are scarcely visible without the aid of the microscope. But they are found always in the same part of the spectrum, and of the same proportional breadth. These vacant, or rayless lines in the solar spectrum are supposed to indicate the existence of certain rays which do not come to us. It is imagined that they may be *absorbed by the sun's atmosphere.*

630. There are certain colored flames, which when examined by a prism, exhibit *spectra* deficient in particular rays, like the solar spectrum when examined by colored glasses. Pure hydrogen gas burns with a blue flame, in which many of the other rays are wanting. Alcohol when mixed with water, affords no other flame but yellow. Most of the salts, when exposed to the blaze of a lamp, give color to the flame as follows:

Salts of soda—homogeneous yellow.
" potash—pale violet.
" lime—brick red.
" strontia—bright crimson.
" baryta—pale apple green.
" copper—bluish green.

631. Color is not an essential property of matter; but it arises from the action of matter upon light. Thus a white cloth reflects all the rays. But when dyed yellow, the particles of the cloth acquire the property of absorbing all the other rays, and of reflecting only the yellow. Bodies that reflect all the rays, appear white; those that absorb all, appear black. Colored bodies decompose light by absorbing some of the rays and reflecting others. The color which a body *seems* to have, is, in reality, *that for which it has no affinity*, and therefore throws it off at its surface, while the other colored rays hide themselves among its particles. In the dark there is no color, for there is no light to be decomposed; therefore, none to be absorbed and none reflected. So true is it, as expressed by the poet, that

"Colors are but phantoms of the day,
With that they're born, with that they fade away,
Like beauty's charms, they but amuse the sight,
Dark in themselves, till by reflection bright;
With the sun's aid, to rival him they boast,
But light withdraw, in their own shades are lost."

630. Different colored flames. How produced.
631. Color not an essential property of matter. Concluding remarks upon color.

PART VII.

ELECTRICITY. MAGNETISM.

LECTURE XXXVIII.

THEORIES OF ELECTRICITY.—MODE OF OBTAINING IT.
CONDUCTORS AND NON-CONDUCTORS.
ATMOSPHERIC ELECTRICITY.

632. From considering the mechanical laws which govern *solids*, we proceed to the investigation of the laws of *liquids*, and next of *air;* then to the phenomena of *sound* as connected with air. We examined the properties of *light*,—that agent which, while it reveals to us other objects, is, itself, a mystery, confounding the wisdom of Philosophers, while it gratifies them by occasional discoveries of new and unexpected properties. We are now to contemplate another power in the machinery of the universe; one, which, though long unknown to man, is around him on every side, and appears connected with almost all the physical changes which are taking place on the globe. This power is called *electricity*.

633. *Electricity is, probably, a material substance.* But such is its subtle nature, that few of the properties common to matter have yet been discovered as appertaining to it. Pervading the earth, its atmosphere, and all terrestial things, it neither affects their temperature nor enlarges their volume. When undisturbed, it is quiet, giving no sensible tokens of its existence. But like the slumbering volcano, it is capable, when roused into action, of exhibiting a terrific force.

634. Electricity was first observed as a property of amber, a resinous substance, called in Greek, *electron*, from whence the

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632. Retrospect of subjects considered. New subject.
633. Is electricity known to be material?
634. Discovery of electricity. Electricity first ranked among the sciences

name, electricity was derived. Plato, and some other ancient writers, stated that amber, by rubbing, might be made to attract light substances, as the load-stone attracts iron. The same property of attraction had been observed in jet, emerald, and some other precious stones. But a few isolated facts and observations only, which seem to have excited little attention among the ancients, were recorded by them.

635. It was not until the last century that electricity took its rank among the sciences. Our distinguished countryman Dr. Franklin, is acknowledged as the author of some of the greatest discoveries concerning the nature of this fluid, and especially its identity with the lightning which flashes in the heavens.

"To electricity," says Herschel, "the views of the physical inquirer now turn from almost every quarter, as to one of those universal powers, which nature seems to employ in her most important and secret operations. This wonderful agent, which we see in intense activity in lightning, and in a feebler and more diffused form traversing the upper regions of the atmosphere in the *northern lights*, is present probably in great abundance, in every form of matter which surrounds us, *but becomes sensible only when disturbed by experiments* of peculiar kinds. Every body is familiar with the crackling *sparks* which fly from a cat's back when rubbed. These by proper management may be accumulated in bodies suitably disposed to receive them, and although then no longer visible, give evidence of their existence by a variety of extraordinary phenomena,—producing attractions and repulsions in bodies at a distance, admitting of being transferred from one body to another under the form of *sparks* and *flashes*; traversing with perfect facility the *substance* of the densest bodies called *conductors*; producing painful *shocks* and *convulsive* motions, and if in sufficient quantity, even death itself in animals through which they pass; and, finally, imitating on a small scale the effect of lightning."

636. When we make use of the term *electricity*, or *electric fluid*, it must be understood that nothing more is implied than the *unknown cause* of electrical phenomena.

Those who advocate the theory of a universal etherial fluid, which, by its vibrations causes the phenomena of light, very naturally consider electricity as intimately connected with that fluid; and as light and heat both usually accompany electrical experiments, we have reason to believe that they all result from one source, but under different and complicated forms. Magnetism and galvanism are known to be produced by electrical excitement; and to the same cause are referred some of the most important chemical changes.

637. *Explanation of Terms.* *Attraction* is one of the most important properties of electricity. On rubbing a glass tube with a dry silken handkerchief, it attracts light bodies, as down, silk, cotton, &c. When a body exhibits electrical appearances, it is said to be *excited*. A body receiving electricity is said to be *electrified*. An electrified body is said to be *insulated*, when it is so situated that its electricity cannot escape. *Conductors* are substances

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635. General characteristics of electricity.
636. What is understood by the term electricity?

which readily transmit the electric fluid; *non-conductors* prevent its free passage. *Glass* and *amber* are both capable of electrical excitement; but the electricity of the one, presents different properties from that of the other. The same difference is observed with respect to various other substances. The term *vitreous* is applied to that electricity which appears on exciting glass and other analogous bodies, and the term *resinous* to that which appears in amber, sealing-wax, and other resinous substances. The term *positive* when applied to electricity is synonimous with *vitreous*, and *negative* with *resinous*.

638. *Theories of Dr. Franklin and Du Fay.* Dr. Franklin's theory of electricity supposes that there is one electric fluid which exists in all bodies, and is naturally in a state of rest. That when the equilibrium is destroyed by friction or any other exciting cause, one body becomes *plus*, or *positively electrified*, while the body in contact becomes *minus*, or *negatively electrified.* Thus when a glass tube is rubbed with a piece of silk, the tube gains and the silk loses electricity.

A theory of a different kind, which was advanced in France, by Du Fay, previous to the time of Franklin's discoveries, is now strongly advocated. This theory supposes the existence of two antagonist electric fluids, called the *vitreous* and the *resinous*, (from glass and resin, the two substances from which they are respectively produced,) which like an acid and an alkali neutralize each other. It is only when separated, that they manifest their peculiar properties, and the most striking appearances are exhibited at the instant in which they unite. As either of these theories satisfactorily explain most of the electrical phenomena, it is not necessary to enter into a consideration of their comparative merits. The theory of Franklin has the advantage of simplicity. According to the analogies of *nature* we should not be inclined to attribute to two agents that which could be effected by one; and by an acknowledged rule in philosophy, no more causes should be ascribed than are necessary to account for the phenomena. Some, indeed, assert that there are phenomena accompanying the transfers of electricity from body to body, and the state of equilibrium it affects under various circumstances, which appear to require the admission of *two distinct fluids*, antagonist to each other, each at-

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637. Attraction. Electrical excitement. An electric body. Conductors and non-conductors. Electricity of glass and of amber. Vitreous and resinous electricity. Positive and negative electricity.

638. Franklin's theory of electricity. Theory which originated in France. The student not obliged to adopt or reject either theory. Why is Franklin's *theory* the more simple? Positive and negative fluids distinguished from *positive* and negative electricity.

tracting to the other, and repelling itself. The terms *positive* and *negative fluids* are sometimes used by the advocates of two fluids, and must be distinguished from *positive* and negative electricity, which refer to the different states of the same fluid.

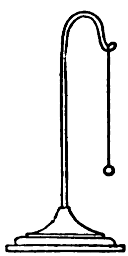
639. *Exp.* 1. Rub a piece of sealing-wax with silk, fur, or flannel, and it will have acquired the power of attracting substances. If a small pith ball be suspended by a silken thread, a feather or bit of cotton will be alternately attracted and repelled by the excited body.

Exp. 2. If a glass tube be rubbed several times in the dark, and the finger be brought within half an inch of it, a spark will be seen between the finger and tube, accompanied by a snapping noise, and a sensation like the prick of a pin.

These experiments prove that electricity is excited by friction, and that *attraction*, *repulsion*, *light* and *sound* are electrical phenomena.

640. The *presence* of electricity, its *nature* and *quantity* may be determined by a very simple instrument called an *electrometer*. The *pendulum electrometer* consists of a glass rod fixed to a stand, and bent at the top. A thread of silk, with a very small pith ball attached, is suspended from the glass hook. By means of this little instrument, it is easy to determine whether the electricity given off by any substance, be vitreous or resinous. When the pith ball of the electrometer is excited by glass, it will be repulsed by any body having the vitreous electricity; and attracted by any body having the resinous electricity. On the contrary, if the pith ball of the electrometer be excited by sealing-wax, it will be repelled by the resinous and attracted by the vitreous electricity.

Fig. 255.



641. *The two kinds of electricity are produced at the same time, the one kind in the body rubbed, and the other in the rubber.* When a glass tube is rubbed with silk or flannel, as much positive electricity is excited in the glass, as there is negative in the silk. *The kind* of electricity depends on the substance rubbed. If dry flannel be rubbed against *smooth* glass, the flannel acquires the resinous, and the glass the vitreous electricity. When two plates of glass, one polished and the other rough, are rubbed against each other, the polished surface has the positive, and the rough surface the negative electricity.

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639 Exp. 1. Exp. 2.

640. Nature and use of the electrometer.

641. Effects upon the body rubbed and the rubber. On what does the *kind of electricity depend?*

642. The following substances become positively electrified if rubbed with either of those mentioned after them, and on the contrary, they become negatively electrified when rubbed with either of those named before them.

1. Fur of a cat,	6. Paper,
2. Polished glass,	7. Silk,
3. Wool and flannel,	8. Sealing-wax,
4. Feathers,	9. Rough glass,
	10. Sulphur.

The fur of a cat, when rubbed against any of the bodies above named, affords the vitreous (positive) electricity. Sulphur, when rubbed against any of the bodies above named, affords the resinous (negative) electricity. Silk becomes negative when rubbed against paper, feathers, &c., but positive when rubbed against sealing-wax, rough glass, or sulphur. Thus when silk stockings have been worn over woolen, sparks and a crackling noise are often perceived on separating them.

Conductors and Non-conductors of Electricity. There is a great difference in the power of bodies to conduct or transmit the electric fluid. Among the conductors are the *metals*, *charcoal*, *living animals*, *flame*, *smoke*, *steam and damp air*. Among the non-conductors are *resins*, sulphur, wax, glass, silk, wool, hair, feathers, &c. The air when dry is a non-conductor, as are all vitreous and resinous substances.

643. Bodies surrounded with non-conductors are said to be insulated, because when excited, their electricity cannot escape. But when they are not insulated, the electricity is conveyed to the earth, which is a conductor. In order to accumulate electricity, therefore, the excited substance must be insulated. If the air, as well as the earth, were a conductor, it would be very difficult to accumulate electricity. Damp air being a conductor, it is quite necessary to the success of the experiments on electricity, that they be performed in dry weather, unless the air of the room be dried by artificial heat.

644. *Electrical Apparatus.* The electric machine is used in order to accumulate large portions of electricity, for the purpose of experiment.

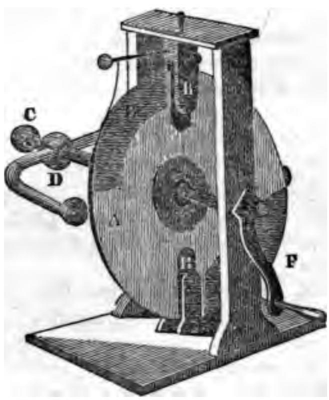
Fig. 256, represents what is termed a *plate machine.* This consists of a circular *glass plate* A, nearly two feet in diameter, turning upon an axis which passes through its center. The plate is rubbed by two pairs of cushions B B. C, called the prime con-

642. Substances remarkable as conductors or non-conductors of electricity.

643. An insulated body.

644. Describe the electrical machine.

Fig. 256.



ductor, is a brass cylinder having two branches, so as to receive electricity from each cushion. E E are pieces of oiled silk passing from the cushions near to the points of the conductor. F is the handle by which the plate is turned. The cushions are stuffed with hair and coated with an amalgam composed of tin, zinc and mercury, a substance which has been found to cause a great degree of electrical excitement when rubbed against glass. When the glass plate is made to revolve rapidly, if the machine is properly prepared and the atmosphere in a dry state, shocks will be felt and vivid flashes of light seen passing over the surface of the glass, and from the cushions to the conductor. The light is supposed to be occasioned by the sudden compression of the air, owing to the escape of the electric fluid. Heat is also evolved, for gun-powder, alcohol and other inflammable bodies are set on fire by the electric spark.*

645. The principles on which the electrical machine operates, are the following: 1. The rubber communicates with the floor by means of a metallic chain, which is a conductor of electricity; 2. The floor communicates with the earth, from whence are derived inexhaustible stores of the electric fluid; 3. By the friction of the glass, positive electricity is acquired by the rubber, and this is attracted and carried off by the metallic points of the prime conductors, in which it becomes accumulated. On presenting the knuckle to the conductor, a spark is seen, and a peculiar prickling sensation is felt. There is no greater mystery in this than there is in the pain we feel on touching a hot iron. In the latter case, it is the passage of caloric into the hand which causes the sensation; in the former case, it is the passage of electricity; and we know no more what caloric actually is, than we do what electricity is, considered in relation to its essence.

* For a description of the Cylinder Machine, see the author's Chemistry for Beginners, page 73.

645. Principles on which the electrical machine operates. Cause of the sensation produced by electricity. Suppose the rubber to have no communication with the earth.

If the communication between the earth and the rubber be cut off, the supply of electricity to the machine would soon be exhausted.

646. The passage of electricity from one substance to another is termed *induction*. Active electricity, existing in any substance, tends always to *induce* the opposite electrical state in the bodies hat are near it.

647. By various experiments it has been found that electricity remains at, or near, the surface of bodies. It is found that in conductors of an *elongated* figure, the electric fluid is accumulated towards the *two ends*, and withdrawn more from the central parts. Thus it is that electrical conductors terminating in a conical point, part with their electricity so readily.

Fig. 257.

648. When the electric fluid is to be collected in large quantities for the purpose of experiments, a vessel, A, called the *Leyden jar** is made use of. It consists of a thin glass jar, coated internally and externally, to within about two inches of its mouth, with *tin foil*. The accumulation of the fluid in this jar is called "*the charge:*" this is effected by connecting the brass wire with the knob at its top, with the conductor of the machine. On working the electrical machine, the fluid issues from it to the jar, rendering the inside positively, and the outside negatively electrified.

649. This charge would remain for a short time, but would be gradually dissipated by the action of the air. But when the charge is to be passed through any substance, the discharging rod B is used. By applying one of the ends to the outside of the jar, and bringing the other towards the knob communicating with the inside, an explosion takes place, and the equilibrium between the inside and the outside of the jar is restored. The charge of a jar which would contain a gallon, is quite sufficient to fire gun-powder, or any other inflammable substance. A single spark will kindle spirits of wine

* So named from Leyden, in Holland, the place where it was first constructed.

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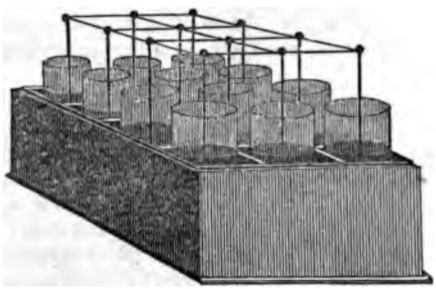
646. Induction.
647. Why conductors are of an elongated conical figure.
648. Explain the construction of the Leyden jar, with the manner in which it is charged.
649. Use of the discharging rod. Electrical battery.

Fig. 258.

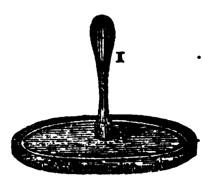


or ether; but when great intensity is required, such as is sufficient to fuse steel wire, deflagrate gold, or silver-leaf, &c., a combination of jars, which may be all discharged at the same instant, is required. This combination is called the *electrical battery*, and is usually constructed as in the figure.

Fig. 259.

650. An instrument called the *spiral tube* serves to render the course of the electric matter visible, and shows its color in a beautiful manner. One end of it is applied to the ball of the conductor, the other end being held in the hand; the spark from the conductor instantly passes from one spangle of the tin foil, on the glass tube, to the other, and brilliantly illuminates the whole. This experiment may be varied at the will of the operator; and drawings or sketches of any kind may be laid down on plates of glass, and thus rendered luminous.

Fig. 260.



651. The *electrophorus* is a simple machine, consisting of an *under* plate or *sole*, B, covered with a *resinous* coat, and an upper plate or cover, A, of metal or wood coated with tin-foil, and having a handle I, of glass, or some non-conducting substance. The resinous plate, being rubbed with a piece of fur, becomes charged with negative, or *resinous* electricity. The upper plate A, is now placed upon the sole, or resinous plate, and the finger being applied to the former, receives electricity, which may be transferred to a Leyden jar, by touching the knob. After repeating this process several times, the jar may be found sufficiently charged to cause a loud report, on the application of the discharging rod, and

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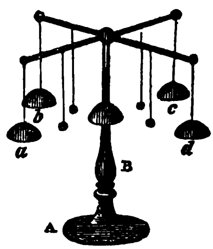
650. Spiral tube.

651. Electrophorus; and the manner in which electricity may be accumulated with it. Is the charge in the Leyden jar, of the same kind of electricity?

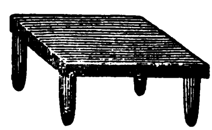
to set fire to cotton. Although the negative or resinous electricity is first excited by rubbing the under plate with the fur, the charge in the Leyden jar is of the opposite kind, viz., the *positive* or vitreous. *The fluid which is obtained by induction being always the opposite of that of the excited body.* Thus, if instead of a plate coated with resin, a glass plate be used, the negative or resinous electricity will be obtained.

Fig. 261.



652. *Electrical bells.* The figure represents four bells, *a b c d*, hanging by brass rods, with a bell fixed on a brass pedestal, A B, and four small brass balls suspended by silken threads. The brass rods which sustain the four balls, being connected with the prime conductor of the electrical machine, becoming electrified, attract the brass balls which hang by silk, and these acting as clappers cause a ringing; the balls having gained electricity by this contact with the bells, fly off, and are attracted towards the middle bell where they discharge themselves. They are now ready to be attracted again by the bells, which are continually receiving new portions of electricity from the electrical machine; and thus the ringing of the bells may be continued as long as the machine is in operation.

Fig. 262.



653. An *insulating stool* is a small foot-stool with glass feet. A person standing on this stool is said to be *insulated*, that is, there is no medium by which electricity can be conducted from him. If a person thus insulated, hold in his hand a chain connected with the prime conductor, his body will become a conductor, giving off electrical sparks to substances presented to it, and attracting such as are sufficiently light; his hair, which is similarly electrified, will rise and diverge in all directions, each single hair mutually repelling and being repelled by the others.

654. *Dancing figures* illustrate, in an amusing manner, some of the properties of electricity, particularly that of attraction and repulsion. Two metallic plates are represented in the cut. The lower one is connected with the floor. The upper plate being electrified by a communication with the prime conductor, attracts towards it light bodies. Let small figures, cut from some light material, such as pith, paper, or the like, be placed on

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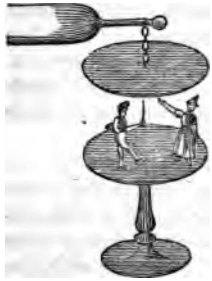
652. Electrical bells.
653. Insulating stool.
654. Dancing figures.

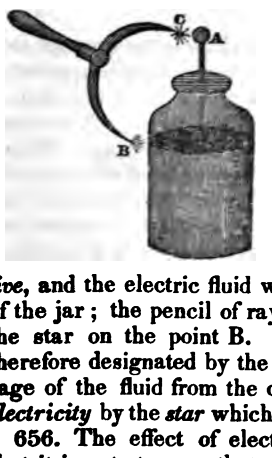
Fig. 263.



the lower plate; on suspending the upper plate at a little distance above them, they are attracted towards it. When the figures touch the electrified plate they acquire electricity, and are, of course, repelled by the upper, and attracted by the lower plate, now in an opposite electrical state. Discharging themselves by contact with the lower plate, they are again negative, and in a condition to be attracted by the positive plate suspended over them. Thus the electrified figures are alternately attracted and repelled by each other, as they are in opposite or similar states of electricity: and a very lively dance among the little excited images, is thus kept up as long as the upper plate continues to receive electricity.

655. The light from the electric spark appears as a *pencil of rays* or as a *star*, according to the species of electric fluid which causes it. A Leyden jar being charged with *positive* or vitreous electricity, its outside coating is negative, or has the resinous electricity. Let the discharging rod, having its ends pointed, be presented, so that one of its points shall be within an inch of the knob of the jar A, and let the other point be as near to the outside coating of the jar; the point C will be illuminated with a *star*, and the point B with a *pencil of light*. This is because the electric fluid, going from the inside to the outside of the jar, (or making the electric circuit) enters at the point C, and issues from the point B. But if the jar is electrified *negatively* on the inside, the outside will then be *positive*, and the electric fluid will pass from the outside to the inside of the jar; the pencil of rays will then appear on the point C, and the star on the point B. The *positive or vitreous electricity* is therefore designated by the *pencil of rays* which indicate the passage of the fluid from the conductor, and the *negative* or *resinous electricity* by the *star* which shows the fluid entering the conductor.

Fig. 264.



656. The effect of electricity upon animals is so remarkable that it is not strange, that when first discovered, it should have

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655. Light from the electric spark varies according to the species of electricity.

656. Effect of electricity upon animals.

excited great attention, and many extravagant notions with respect to it should have prevailed. Men who had acquired some practical knowledge of electrical apparatus, but were ignorant of philosophical principles, travelled about, astonishing the credulous, and deluding the sick, lame, and impotent with the fallacious hope that by submitting to the process of "*electerizing*," that is, to receive a shock from a charged jar, they would obtain a certain cure for all their diseases.

657. *The animal system is a good conductor of electricity.* If any number of persons join their hands, and the first in the circle presents a discharging rod to the outside coating of a charged Leyden jar, at the same time the last in the series touches with another rod, the knob of the jar, thus forming an *electric circle*, a shock is felt throughout the whole circle, and by every one in it at the same instant. If the jar is charged with positive electricity, the fluid will issue forth from the knob of the jar, and run through the circle till it is discharged through the person who touches the outside coating of the jar; but if the outside coating is positive, the fluid will pass in a contrary direction.

So rapid is the *motion* of electricity, that it seems to be instantaneous; but like light it is doubtless progressive, though its velocity is inconceivably great.

Atmospheric Electricity.

658. There is always more or less electricity in the atmosphere. This may be ascertained by experiments with a simple apparatus called the *electrical kite*. This has for a conductor, a fine metallic wire twisted with the cord which forms the string. This conductor is insulated by being attached to a silken string. When this kite is raised in the atmosphere, the presence of electricity is manifested by an electrometer connected with the lower end of the conductor. When the electricity of the atmosphere is excited, as manifested by thunder clouds, there is much danger in thus drawing down the lightning.

659. The electricity drawn from the clouds by the electrical kite, or a conducting rod, may be accumulated in a Leyden jar; and its properties are found to be the same, as those of the fluid produced by the electrical machine. Doctor Franklin observing various electrical phenomena, was led, by reasoning from analogy, to believe lightning an effect of the same cause. This theory he proved by experiments made with an electrical kite during a thunder storm. The following are some of the resemblances pointed out by this Philosopher, between electricity and lightning.

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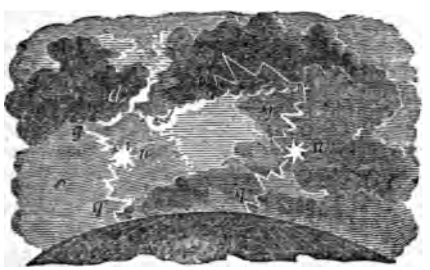
657. Electric circle. Motion of electricity.
658. Electrical kite.
659. Nature of atmospheric electricity.

660. 1. The zigzag form of lightning corresponds exactly, in appearance, with a powerful electric spark passing through a considerable interval of air. 2. Lightning most frequently strikes high bodies, as the summits of hills, high trees, towers, spires, chimneys, &c. So the electric fluid, when passing from one body to another, always seizes on the most prominent parts. 3. Lightning and electric matter are both found to pass most readily through those substances that are good conductors, such as metals, water, &c., and to avoid those that are non-conductors, as glass, silk, sealing-wax, resins, &c. 4. Lightning inflames combustible bodies; the same is readily effected by electricity. 5. Metals are melted by a powerful charge of electricity; this is one of the most common effects of a stroke of lightning. 6. Lightning fractures and disperses all brittle substances; the same holds true with respect to the electric fluid. 7. Lightning often produces blindness; the same effect is found to be produced on animals when subjected to a strong electric charge. 8. Animal life is destroyed by lightning; strong discharges of the electric fluid will produce the same effect. 9. The magnetic needle is similarly affected by lightning and electricity, and iron may be rendered magnetic by both causes.

661. The charging and discharging of electrics is a miniature representation of the sublime process which is going on in the heavens during a thunder storm. Thus a cloud positively electrified, will draw towards it, clouds that are negatively electrified; when these clouds approach within what is termed their *striking distance*, the fluid darts from the positive to the negative cloud; the explosion produces a loud report, which being echoed from cloud to cloud, produces the rolling noise called thunder. It frequently happens that the lightning during a thunder storm is seen darting from the clouds towards the earth, and there producing dreadful effects. This may be caused by the earth, over which the storm happens, being, at the time, negatively electrified. The letter *a* represents a portion of the earth's surface; *c*, the lower or non-conducting part of the atmosphere, *d d*, the clouds charged with electricity; *g g*, the positive electricity of the clouds, met by the negative electricity *q q*, of the earth; *n n*, the points where the two electricities meet, and where the explosion takes place.—This explosion is often very terrible, accompanied with intense lightning and astounding thunder, and rending in sunder everything in its way. Buildings that are lofty are much exposed to its effects; and hence the necessity of having metallic *conducting-rods* raised on them. Green trees being good conductors of electricity, those which rise high into the atmosphere often attract the fluid towards them; it is, therefore, highly dangerous to go under them for shelter during a thunder storm. It is safer to remain in the open air at the distance of about forty or fifty feet from trees or houses. Within

Fig. 265.



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660. Analogies between lightning and electricity.

661. Discharge of electricity from the clouds. Conducting-rods. Danger of seeking the shelter of trees in a thunder storm.

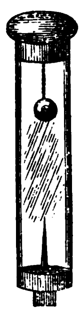
doors, the middle of the room should be preferred, and such a position might be rendered still more safe, by standing on a glass-legged stool, or hair mattress, or even a thick woollen hearth-rug. In a thunder storm the middle story of a house is considered the most secure, and the cellar the most exposed part of it.

662. Thunder is supposed to be caused by the *motion of the air rushing in to fill the void made by the sudden passage of the electric fluid. Lightning is supposed to be caused by the sudden condensation of the air, produced by the compressed force of the electric fluid.** The lightning is seen before the thunder is heard, because light travels faster than sound.

Aurora Borealis.

663. It is now generally believed, that the beautiful meteor, called the *Aurora Borealis*, or northern lights, is occasioned by the passage of electricity through the upper regions of the atmosphere, where the air is some thousand times more rarefied than at the earth's surface.

Fig. 266.



The figure represents a large glass tube fitted with a brass cap at the top, from which projects into the tube a wire terminating in a ball. At the lower end of the tube, projects a similar wire, but pointed at the extremity. This tube, being exhausted by means of an air-pump, on applying the electrical machine, the electrical fluid will pass between the two wires, in a diffused luminous stream, having all the characteristic appearances of the northern lights. There is the same variety of color and intensity within, the same undulating motion and occasional coruscations; the streams exhibit the same diversity of character, at one moment minutely divided in ramifications, and at another beaming forth in one body of light, or passing in distinct broad flashes.

664. The cause of the *aurora borealis* was long unknown. At present, Philosophers agree in referring it to electrical agency. It appears generally in the form of a luminous arch above the northern horizon, and extending from east to west across the heavens; but never from north to south. Those who witness the peculiarly soft, and brilliant light produced by electricity in passing through a tube of highly rarefied air, cannot but be struck by its resemblance to the beautiful illumination of the *aurora borealis*, and will readily believe them to be effects of the same cause.†

* In this case, it is supposed caloric is brought from a latent state in the atmosphere to a free state, in which it is accompanied by light.

† At about nine o'clock on the evening of January 25, 1837, at Brattleborough, Vermont, while the author was engaged in preparing this work, she

662. Cause of thunder and lightning.

663. Aurora borealis, its connection with electricity. Experiment to show the effect of electricity upon rarefied air.

664. Supposed cause of the aurora borealis.

665. Though the name *Northern Lights* has been given to this phenomenon, the same luminous appearances are occasionally exhibited in the southern hemisphere. As such sublime displays of created effulgence are never made in vain, these *polar accumulations of the electric fluid* doubtless subserve some wise and conservative principle in the economy of nature. May it not be that, by this means, an electric circuit is formed between the equator and the poles, and the equilibrium in the earth's electricity thus maintained?*

LECTURE XXXIX.

MAGNETISM.—DIP OF THE MAGNET.—DEVIATION OF THE COMPASS. THEORY OF MAGNETISM.—THE COMPASS.

666. MAGNETISM *is the science which treats of the properties and effects of the magnet.* Accustomed as we are to examine things by our external senses, it requires some faith to believe in the existence of matter which is not manifest to one of these senses. The *electric fluid,* though neither tangible, nor visible, in its effects, is seen, heard and felt. *Magnetism* is a silent, invisible and intangible agent; but we see its *operations,* and therefore we give credence to philosophers who assure us that these effects must proceed from some cause, the name of which they call magnetism or the magnetic fluid. Would it not be very inconsistent, should these philosophers attempt to overthrow the christian's faith in the existence of God, on the ground that he has no *sensible* evidence of such a being? A bar of iron attracts towards it a small bit of steel;—this, the philosopher says, is caused by the power of magnetism. Must so simple an effect be the result of a cause, and, yet, the universe, itself exist uncaused? Shall this regularity, order, and harmony of the creation be ascribed to accident, chance, or nothing, because the philosopher has never *seen* the Power which created and upholds all things;—because the power is not *embodied* and *directly revealed,* in all its ineffable magnificence, to the bodily sense of man? This argument may, to some, appear unconnected with the subject of our present lecture, but philosophy and religion have been too long viewed as entirely distinct,

was called to witness one of the most splendid exhibitions of this phenomenon, which has ever been seen in our latitude. It can scarcely be expected that any persons now living will ever again see so sublime a display of Almighty power in a similar form.

* Chemical Electricity is treated of in the Author's larger work on Chemistry.

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665. Northern lights not confined to the northern hemisphere. Suggestion with respect to this phenomenon.

666. Definition of magnetism. Reflections suggested by the subject of magnetism. Religion and philosophy not entirely distinct.

if not at variance with each other. The young need to have their faith in an *unseen, superintending providence,* strengthened by various considerations; and when, in the course of their scientific pursuits, arguments leading to this end present themselves, it is not to be counted as time lost if they pause to reflect upon them.

667. We admit the existence of an *unknown cause* of certain phenomena called *magnetism,* and the bodies in which this unknown cause operates are called *magnets.*

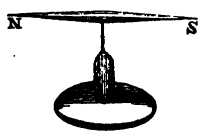
The phenomena of magnetism are, 1st. *attraction and repulsion;* 2d. *the power of the magnet to impart its properties to other masses of steel or iron;* and 3d. *its tendency to point towards the poles of the earth.*

668. A magnet may be either natural or artificial. The natural magnet is an *oxide of iron,* of a dark grey color, very heavy, and with a metallic lustre. It has long been known as the *loadstone.* It is usually found in beds of iron ore, in irregular masses of a few inches in diameter; but, sometimes, in larger quantities. There are natural magnets of more than one hundred pounds weight, with the power of lifting two hundred pounds of iron by means of their attractive property. Every magnet has two opposite points called *poles;* and at these points, the attractive power is greatest. The poles are called the north and south poles, (see N and S in the figure) accordingly as they point to the north or south pole of the earth. The imaginary straight line, N S, which joins the poles, is called the axis. If a magnet be immersed in iron filings, they will attach themselves to it until it is completely covered. At the poles of the magnet, the attracted filings will stand erect (as at Fig. 267;) but they gradually become less perpendicular, till, in the center, they lie in a horizontal position. The curves thus formed, are called *magnetic curves.*

Fig. 267.

669. The magnetic power like electricity, may be transmitted from one body to another. Thus by rubbing bars of iron or steel* with a magnet, an *artificial magnet* is formed, possessing all the properties of the natural one. Suppose a magnetized steel needle to be exactly balanced upon a pivot, like that of the mariner's compass,

Fig. 268.



* Steel is the *carburet of iron,* or *iron* combined with *carbon.*

667. Magnets. Phenomena of magnetism.
668. Loadstone. Where found. Poles of the magnet. Iron filings attracted by a magnet. Magnetic curves.
669. Transmission of the magnetic power. Artificial magnet. Polarity.

so that it can move freely towards any point, it will not rest until its poles point nearly north and south. If this position is changed, the needle will vibrate until it settles in the same line as before. This is called the *polarity*, or *directive property* of the magnet.

Dip or Inclination of the Magnet.

670. The two poles of the magnet, when at liberty to move freely, do not lie *exactly* in a horizontal direction, but one pole inclines a little downwards, thus proportionally elevating the other pole. This is called the *inclination* or *dip* of the magnet. In going north, the north pole of the magnet is depressed; and the nearer the pole, the greater the depression. It is supposed that if the needle could be carried to the pole it would assume nearly a vertical position, its northern pole pointing perpendicularly downwards, and its southern pole upwards.

Suppose N S to be a magnetic bar whose north pole is N, and whose south pole is S; if a magnetic needle turning on a point were presented to the magnetic bar, it would assume the various positions of the arrow in

Fig. 269.

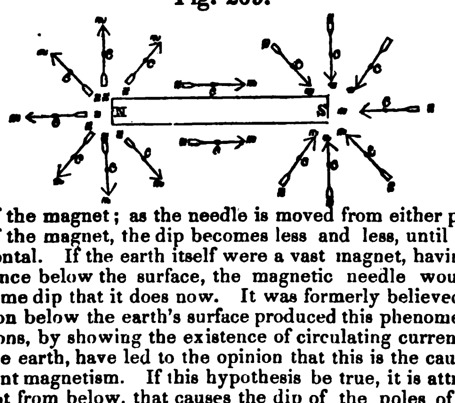
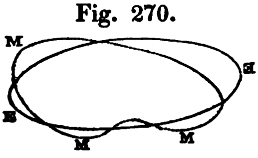


Fig. 269, *n* and *s* representing the north and south poles of the needle, and *c* the pivot on which it turns. It will be seen, that the south pole of the needle points directly to the north, and the north pole of the needle to the south pole of the magnet; as the needle is moved from either pole towards the center of the magnet, the dip becomes less and less, until at the center it is horizontal. If the earth itself were a vast magnet, having its poles at some distance below the surface, the magnetic needle would show precisely the same dip that it does now. It was formerly believed that magnetic attraction below the earth's surface produced this phenomenon; but late observations, by showing the existence of circulating currents of electricity around the earth, have led to the opinion that this is the cause of the earth's apparent magnetism. If this hypothesis be true, it is attraction from above, and not from below, that causes the dip of the poles of the magnetic needle. There are reasons to believe that the phenomena of magnetism are caused by opposite electricities; in which case the poles of the magnetic bar and needle are attracted by antagonist electrical fluids.

Fig. 270.



671. That line around the earth where the magnetic needle has no dip, or maintains a horizontal position, is called the *magnetic equator*. This does not coincide directly with the earth's equator, E E, but may be

670. What is meant by the dip of the magnet? How is the subject illustrated?

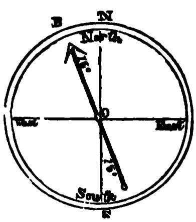
671. Magnetic equator.

considered as a great circle surrounding the earth, and inclined to its equator, at an angle of about 12 degrees. It crosses the equator at several different points. This line is represented by the letters M M M.

Deviation or Declination of the Compass.

672. The magnetic needle moving freely, does not point *directly* to the poles of the earth; this variation is called by mariners the *declination* or *deviation* of the compass. Although the deviation of the magnetic needle was known to some philosophers, two hundred years before the time of Columbus, yet it was not generally understood by mariners. For when the crew of that navigator, on his first voyage of discovery, learned that the needle of their compass did not point directly to the pole, they were alarmed, and losing all confidence in that only sure guide to the mariner, grew more mutinous towards their commander, through fear that he would never be able to conduct them back to their homes.

Fig. 271.



Due allowance being made for the variation of the magnetic needle, the exact points of the compass may be ascertained Thus suppose the line N S to represent the true meridian, or a line drawn due north and south, and that which is drawn at right angles represents the equator, or a line from east to west. The magnetic needle does not fall on the meridian, as it would do if it pointed directly to the north pole, but *deviates* from it, making the angle B O N, the line B O being 15 degrees north This shows the *declination* or deviation of the needle; when this deviation is towards the west, as seen at B, the *declination* is said to be 15 degrees westerly.

673. By the *magnetic meridian* is meant a vertical circle in the heavens, supposed to be drawn through a line in which the needle naturally places itself. This meridian does not, as we have seen, always correspond to the geographical meridian, though there are places in which the magnetic needle, freely suspended, points directly to the poles of the earth, in which case the meridians coincide. Lines drawn on the globe through all places where the magnetic and geographical meridians coincide, or where the needle points due north and south, are called *lines of no variation*. But such lines are themselves variable; as the direction of the needle is not constant in the same place, but is subject to change, through the influence of some unknown cause.

In 1657, according to observations then made in London, there was no variation, the needle pointing directly to the north pole of the earth, and consequently coinciding entirely with the earth's meridian. After this period it began to vary a little towards the west. This variation continued

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672. What is meant by the deviation of the compass? Method of calculating the variation of the needle.

673. Magnetic meridian. Lines of no variation changing place. Magnetic poles of the earth.

progressively until 1818, when the angle of declination was 24° 36 minutes west. Since then, it has been slowly inclining towards the east. This deviation of the compass to the eastward and westward, seems to resemble the oscillations of a pendulum, which moving slowly over an arc of many degrees of the earth's surface, should require some hundred years to go from one extremity of the arc to the other.

To account for the phenomenon of the declination of the compass, it has been supposed that there are magnetic poles constantly revolving, and that these poles do not coincide with the poles of the earth, except at very long intervals. Late observations have rendered it probable that there are magnetic poles in each hemisphere. One has been discovered in Siberia; and Ross and Parry, in their late reports of discoveries in the polar seas, state that there is also an American magnetic pole, about 180 degress distant from that on the eastern continent.

Theory of Magnetism.

674. In observing the phenomena of magnetism we *see* no agent, we *hear* nothing to inform us of its action, and we can feel or touch nothing which gives evidence of its existence. But we perceive the *effects* of the agent called magnetism. When we see filings of iron, or a steel needle moving towards a bar of iron, neither impelled nor drawn by any perceivable external force, and adhering with tenacity after they have come into contact, we perceive something for which we cannot account, otherwise than by referring it to a power called magnetism residing in the iron. We are more struck with this phenonemon, than with the attraction of gravitation, because it is less common; and yet it is no more wonderful that the needle should move towards the iron bar, than that the apple when loosed from the bough, should move towards the earth. But while the attraction of gravitation is an universal principle, that of magnetism is confined to a very few substances, chiefly to iron and steel, and this limitation renders its operations still more mysterious.

675. But though magnetism works in silence and obscurity, while electricity is attended by the flash, the thunder, and the shock, we have reason to believe they are but different modes of operation of one, and the same agent.

1st. Magnetism and electricity, alike consist of *two species;* the *northern* and *southern* polarities,* and the *positive* and *negative electricities.*

* Called also *boreal* (northern) and *austral* (southern) magnetism.

674. Magnetism known only by its effects.

675. Reasons for believing that magnetism and electricity are the same agent. 1st. With regard to the two species. 2d. Similarity of laws. 3d. Effect of combination. 4th. Diminution of force according to the square of the distance. 5th. Communicated by induction. 6th. Two theories of magnetism corresponding to the theories of electricity.

2d. They are governed by the same laws, viz., that similar powers repel, and dissimilar powers attract each other.

3d. The magnetic influence is destroyed by the combination of the two polarities, and the electric action ceases on the union of opposite electricities.

4th. The force, both of magnetism and electricity, varies, inversely, as the squares of the distance. By comparing the number of vibrations of a magnetized needle, during the same time, at different distances from the magnet, it is found that the magnetic intensity, like every known force proceeding from a center, diminishes with the distance; and, as in the attraction of gravitation, diminishes *in an inverse ratio* of the square to the distance. A magnetic needle, being carried out of the direction in which it naturally rests, and left free again, vibrates in a manner similar to the vibrations or oscillations of a pendulum, until it has returned to its natural position. The greater the magnetic intensity which influences the needle, the greater will be the velocity of its vibrations, as the pendulum vibrates most rapidly, when most influenced by gravity. So it has been found by experiments, that the force of electrical attraction and repulsion, varies as the square of the distance from the excited substance. The reciprocal action of magnets and the electrical fluids are, therefore, subject to the laws of mechanics.

5th. Magnetism and electricity may both be communicated to other bodies by *induction*. But magnetism cannot, like electricity, be transferred from one body to another. By induction is meant, that magnets and excited electrics communicate their properties to other bodies in contact with them, by which process they are not, themselves, deprived of any portion of their magnetism or electricity. By the transfer of electricity is meant, that an elec trified body gives off its electricity to another body. The process of induc tion is quiet; while that of transferrence is accompanied by light and sound.

6th. The phenomena of magnetism, like those of electricity, have been explained on the supposition of one fluid existing in the state of *plus* and *minus*, or positive and negative; and the contrary hypothesis of two fluids. Those who advocate the hypothesis of one magnetic fluid, suppose that in the magnet, while there is a surplus at one end or pole, there is a deficiency at the other. The surplus or positive pole is said to be *plus* magnetic, and the deficient or negative pole to be *minus* magnetic. This is according to Franklin's theory of electricity. The theory of *two magnetic fluids* corresponding to the doctrine of the two species of electricity is now generally received. According to this, in the particles of iron, and in all bodies in which iron is found, are lodged two fluids or forces, the one predominating at one end, and the other at the opposite end; each particle attracting those particles in which the *opposite* fluid prevails, and repelling those in which a similar fluid resides; and this attraction or repulsion is proportioned to the inverse square of the mutual distances of the particles.

Electro-Magnetism.

676. Lightning and the Aurora Borealis, which are electrical phenomena, are observed to have great power in disturbing the polarity of the compass;* and it has recently been discovered by Pro-

* At the time of the great Aurora Borealis of Jan. 25, 1837, the magnetic needle was observed to be remarkably disturbed.

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676. Origin of the theory of electro-magnetism. Experiments made to prove the connection between electricity and magnetism.

fessor Œrsted of Copenhagen, that a current of galvanic electricity produces similar effects. This discovery has given rise to the theory of *electro-magnetism.*

"The connection of electricity and magnetism," says Herschel, "had long been suspected, and innumerable fruitless trials had been made to determine the question. The phenomena of many crystallized minerals which become electric by heat, and develop opposite electrical poles at their extremities, offered an analogy to the polarity of the magnet, so striking, that it seemed hardly possible to doubt the connection of the two powers. The development of a similar polarity in the voltaic pile, pointed strongly to the same conclusion Of all the philosophers who had speculated on this subject, none had so pertinaciously adhered to the idea of a necessary connection between the phenomena as Œrsted. Baffled often, he returned to the attack; and his perseverance was at length rewarded by the complete disclosure of the wonderful phenomena of electro-magnetism. There is something in this which reminds us of the obstinate adherence of Columbus to his notion of the necessary existence of the new world; and the whole history of this beautiful discovery may serve to teach us reliance on those general analogies and parallels between great branches of science, by which one strongly reminds us of another, though no direct connection appears; and that such analogies are indications not to be neglected, of a community of origin."

677. Though the *connection which exists between light and magnetism* is obscure, its existence is certain. It had been known, for many years that the violet ray of the solar spectrum has the power of rendering iron magnetic. In 1825, Mrs. Somerville, of England, made a series of experiments by which she proved that the indigo, blue, and green rays, as well as the violet ray, possess a magnetizing power.*

Mariner's Compass.

678. The most important application of magnetism is found in the *mariner's compass.* In order to trace the meridian line which may point out the north and south, recourse may be had to astronomical observations, as the motion of the sun and stars determines that direction. But the heavenly bodies are sometimes obscured, and in darkness and storm, the mariner's compass is the only dependance of the seaman. Before its discovery long sea-voyages were not attempted; for if the mariner lost sight of the shore, he might wander far from his native land, with no pathway upon the trackless ocean to direct his return, nor any index to point out the proper direction. Like a blind man attempting unaided to grope his way to a distant city, he might be going in a

* For a description of Morse's Electro-Magnetic Telegraph, see the Author's stereotype edition of Familiar Lectures on Chemistry, page 68. For other late discoveries in this science, see the same work.

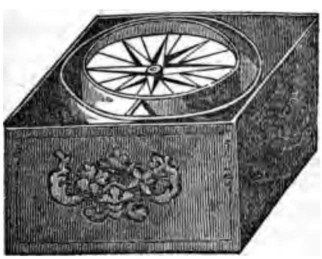
677. Connection between light and magnetism.
678. Utility of the mariner's compass.

direction opposite to the place of his destination. Without the aid of the compass, Columbus might vainly have reasoned upon the existence of another continent; for, with all his boldness, he would never have dared to venture upon the untried ocean with no guide but the uncertain stars.

679. The inventor of the mariner's compass is not known; and it is even doubtful at what period, or by what nations, magnetic polarity was used for determining the direction of places on the earth's surface. It is supposed that a rude form of the compass was invented by the Tartars, to guide them in their wanderings over land; and that they imparted a knowledge of the instrument to the Chinese. The Crusaders, on their return from the East, brought it into Europe, as they did many other valuable improvements in the arts and sciences, gleaned among the remnants of once powerful and enlightened nations.

680. The compass first used was a very imperfect instrument, consisting of pieces of the natural loadstone fixed on cork or light wood, so that it might float on the surface of the water in a dish, on which were marked the cardinal points of the compass. In the compass now used, the magnetic needle is placed within a small box of brass, covered with glass, and so fixed as to retain a horizontal position in all motions of the ship. The needle is generally a thin, flat plate of steel, tapering towards each end, and, to prevent friction, turning on the point of an agate, one of the hardest of minerals, for a pivot. Beneath the needle is a circular card, on which are described two circles, one divided into 360 degrees; and the other into 32 equal parts called points of the compass; of which the four, viz., north, south, east, and west, are called cardinal points, while intermediate between these are the points N E or north-east, S E or south-east, S W or south-west, N W or north-west; N b E is north by east, N N E is north of north-east, N E b E is north-east by east, &c.

Fig. 272.



681. The *surveyor's compass*, used in surveying land, and the *pocket compass* indispensable to the traveller in making his way through a pathless forest, are constructed upon the same principles as the mariner's compass, modified so as to suit the uses for which they are intended.

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679. Inventor of the compass.
680. First compass which was used. Compass now used.
681. Surveyor's compass and pocket compass.

PART VIII.

CELESTIAL MECHANICS, OR ASTRONOMY.

LECTURE XL.

INTRODUCTORY REMARKS.—ARMILLARY SPHERE.—THE SOLAR SYSTEM.—PLANETS.—COMETS.—APPLICATION OF MECHANICAL LAWS TO PLANETARY MOTION.

682. MAN is a being of so transient an existence, so limited in faculties, and so blind to the designs of the Almighty, that it seems, in no small degree, wonderful that he should presume to scan and measure the objects by which he is surrounded. The child, beholding the canopy of heaven, feels a mysterious awe steal upon his spirit. He beholds that for which the surface of the earth around him has no parallel, and his feeble intellect becomes bewildered in the contemplation of the celestial glories. There is connected with the study of the celestial bodies, a kind of reverence, a feeling that we tread on consecrated ground. Were science for the first time about to scale the heavens, and attempt to measure the magnitudes, determine the motions, and compute the distances of its distant luminaries, how bold and hopeless would seem the enterprise! Should we not exclaim, "It is enough for mortals to learn the nature of the terrestial objects around them, without presuming to understand the laws which govern the celestial spheres."

683. It is not left for the moderns to take the first steps in astronomy; the ancients had much more correct notions of this sci-

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682. Reflections on commencing the study of celestial -
683. Antiquity of astronomy. Impediment to its pro

ence, than of the physical nature of the objects by which they were immediately surrounded. Man in the earliest ages was led to contemplate the heavens;—the shepherds of the east, in their night-watches on the plains of Babylon and Chaldea, made many important observations on the motions of the celestial bodies. A new star, seen by the wise men of the east, was a token to them that the Messiah was born; and following its guidance, they traveled westward, till the star stood over a little village of Judea called Bethlehem, "where the young child was."

Astronomy was that branch of physical science which the ancients cultivated with most success. Notwithstanding their imperfect means of measuring time and space, they had learned the motions of the sun and moon so as to be able to predict eclipses with some degree of accuracy. The progress of astronomy was greatly impeded by the belief in the doctrines of Aristotle, which taught, that the celestial bodies, in their motions, were governed by laws peculiar to themselves, and bearing no analogy to those which regulate the motions of terrestial bodies. But there were those, who, from age to age, attempted to throw off the chains which bound the intellect of man; and faint glimmerings of light occasionally broke forth, showing the true pathway of science.

684. But it was not until the time of Newton, that the motions of the heavenly bodies were explained, by the simple law, "that every particle of matter attracts every other particle of matter in the universe, with a force proportionate to the product of their masses directly, and the square of their mutual distance inversely. This law once established, what before seemed *regularity without a plan*, appeared a beautiful and harmonious system. Philosophers were ready to ask, "is this all?" and to wonder that they had not before discovered what was so simple. The true mechanism of the heavens was first taught, and proved by Newton. He not only established his theories by the most plain and conclusive arguments, but bringing mathematics to his aid, conclusively demonstrated the truth of his propositions.

The pupil must not expect in these familiar lectures, designed to give but the outlines of philosophy, an attempt to explain all the phenomena of the heavens, or to make him acquainted with but a small part of the brilliant discoveries which illuminate the *Principia** of Newton, and the labors of his successors. Astronomy, though considered as a branch of Natural Philosophy, is of itself a vast and comprehensive science. Our object is to impart some knowledge of *celestial mechanics*, by which we mean those mechanical phenomena of the heavens, which may be explained by a reference to the *laws of motion, attraction*, and *gravitation*. By these well established laws and principles, the revo-

* This is the title of Newton's work on Natural Philosophy: to *understand* which has been called the test of a great mind.

684. Newton's explanation of the laws of attraction. Newton's theories.

lutions of the planets and their satellites in their orbits, and their rotation on their axes, are all accounted for.

685. *Celestial mechanics may be defined, the science which teaches the magnitudes and distances of the heavenly bodies, their various motions, and the laws by which they are governed.*

686. When we stand upon an open plain, and look around us, we perceive, on all sides, a circle where the earth and sky appear to meet. This circle is called the *horizon*. On looking upwards, we see what *appears* a concave hemisphere. In the night it is spangled with brilliant gems, many of which seem less than the diamond in a finger ring, while a body, which seems much larger than any of the stars, illumines the earth with a mild but splendid light. In the day, all these lesser lights appear to have vanished, and one luminary with bright and piercing beams, alone is seen to move over the blue concave vault.

But all these *appearances* are, in a degree, illusory. What seems *to be the blue sky*, is, in reality, only the body of air around us which decomposes the rays of light from the sun, and, absorbing all the other rays, reflects only the blue. The tiny, twinkling star is, in reality, a sun, millions of times more vast in its dimensions than the world we live in. The moon, which looks larger than any star, is, in reality, the smallest of all the heavenly bodies which are seen by the naked eye. But the moon being much nearer to the earth, than any other celestial body, appears larger. Examine the moon through a powerful telescope, and you see, as if near us, a very large globe apparently suspended in air, and exhibiting on its surface the outlines of mountains, valleys, and even seas and volcanoes. In the day, there are stars in the heavens above us the same as at night; but the lesser lights of the heavens are not visible in the presence of the greater luminary

Again, the celestial bodies *appear* to rise in the eastern horizon, mount up to the meridian, and then sink in the west; but it is, in reality, our own *motion*, and not theirs, which causes these phenomena. And the blue vault of heaven is but an optical illusion. The stars, which seem set near each other in the etherial arch, are posted in various parts of infinite space, many millions of miles distant from us, and from each other, and are probably suns in the center of other systems of worlds. The body of atmosphere which surrounds our globe, and through which rays of light from the celestial luminaries penetrate, extends but about *forty-five* miles in depth. Beyond this, we know not what may fill even the spaces between the globe of earth which we inhabit, and the neighboring planets in our own solar system. Some have imagined the existence of a subtle fluid, called ether, whose vibrations produce the impression of light. Others suppose a fluid which, moving in currents, impels the celestial bodies, and produces their various motions. But we can never demonstrate the truth of these hypotheses, at least, until some new discovery shall give us powers which we do not now possess.

687. As the earth and its divisions are represented upon a sphere called the *terrestrial* globe, so the heavens are delineated upon a *celestial* globe exhibiting the situation of the various clusters of stars which appear there.

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685. What is the science of celestial mechanics?

686. Appearance of the heavens. Difference between appearance and reality in respect to the heavens. Why the stars are not visible in the day. Apparent motion of the celestial bodies. Cause of the apparent motion. Distance of the celestial bodies. Hypothesis of fluids beyond our atmosphere.

687. Celestial globe.

But the convex surface of a celestial globe represents the apparent concave of the heavens, and therefore must fail to give us correct notions of actual appearances. Some of the universities of Europe are furnished with celestial globes sufficiently large to admit several persons within. On the inner surface are painted the celestial bodies, and the various circles which astronomers imagine in the heavens. By the revolution of this artificial sphere, the spectators within, see stars rise, ascend, and set, as they appear to do in the real hemisphere.

688. That point of the heavens over head is called the *zenith*, the point directly opposite, or under foot, is called the *nadir*.

The fixed points round which the sphere of the heavens is supposed to turn, are the *poles* of the celestial sphere, or of the heavens, and a line drawn from one pole to the other, is called *the axis of the heavens;* around this line the celestial bodies seem to revolve every day.

Fig. 273.

689. The *Armillary Sphere.** This is a representation of the earth as situated within a revolving sphere, (Fig. 273,) where various lines and circles are delineated.

1st. The *axis of the earth.* This is an imaginary line passing through the earth's center, and extending on each side, to the poles of the celestial sphere.

2d. The *meridian.* If you point directly over head and move your finger towards the south pole, you will describe a line which the sun crosses just at noon. This line is called a *meridian.* Suppose this line extended so as to form a complete circle around the heavens; it is evident that all the celestial bodies must cross this meridian twice in 24 hours. The sun crosses it at mid-

* From the Latin *armilla*, a bracelet, ring or circle.

688. Zenith and nadir. Poles of the celestial sphere. Axis of the heavens.

689. Armillary sphere. Axis of the earth. Meridian. Equator. Zodiac. *Horizon.* Colures. Polar circles Tropics.

night as well as at noon; and the star which we may see crossing our meridian at midnight, will, at noon, cross the meridian on the opposite side of the globe. The figures on the meridian represent degrees. From the equator to each pole, is one quarter of the celestial sphere, or 90°; and no star can be more than ninety degrees distant from the horizon.

3d. The *Equator* or *equinoctial line*, is a broad belt encircling the middle of the earth from east to west.

4th. The *Zodiac* or *ecliptic*, represents the sun's *apparent* path in the heavens; this is the earth's *real* path or orbit.

5th. *Horizon;* this astronomical circle is called the *rational* or true horizon, and represented as encompassing the globe in the middle, or as 90° distant from the zenith and the nadir. It is represented on the artificial globe by a broad plane of wood. This horizon is distinguished from the circle where the sky appears to touch the earth and sea, called the *sensible horizon.*

6th. The two *Colures*, are two meridians which pass through the poles of the sphere; they are called the *equinoctial** and *solstitial*† *colures.* The equinoctial colure passes through two points in the heavens, called the *vernal and the autumnal equinoxes.* When the sun arrives at either of these points, the nights are of the same length as the days. The solstitial colure passes through two points called *solstitial points;* because when arriving at either of those points, the sun seems to remain stationary for several days.

7th. *Arctic and antarctic circles*, are northern and southern polar circles at the distance of 23½ degrees from the poles.

8th. *Tropic of cancer* and *tropic of capricorn*, are circles parallel to the equator at the distance of 23½ degrees from it.

690. *The earth appears* in the center of the celestial sphere. In terrestrial globes, the various circles delineated in Fig. 273, are usually *marked on the surface*, except the meridian, which is a brazen circle surrounding the globe, and dividing it into eastern and western hemispheres, and the horizon, which is a circular plane of wood dividing the globe into upper and lower hemispheres. By observing the ecliptic and other circles drawn on the surface of the terrestrial globe, or a map of the earth, the pupil often acquires erroneous ideas. The figure in which we have represented the astronomical circles may rectify these notions. There is no real axis passing through the earth or the celestial sphere. The ecliptic or path of the earth around the sun is assumed for astronomical purposes. The earth in its rapid motion around the sun, in reality no more leaves a track to mark its pathway, than the ship leaves its traces upon the pathless ocean. But yet for nearly 6000 years has the earth pursued one undeviating course, completing with perfect regularity its annual revolution.

The cause of the planetary motions we shall consider after having made

* *Equinoctial*, literally signifies equal nights.
† *Solstitial*, literally signifies, the sun standing still.

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690. Manner in which the circles described are usually represented on the artificial terrestrial globe. How may erroneous ideas be acquired?

some observations on the celestial bodies which, in their united effects upon each other, produce these motions.

THE SOLAR SYSTEM.

691. Astronomers suppose that the *universe is composed of an infinite number of systems*, or families of worlds, each sun being connected with every other planet in its system or family, by ties that cannot be broken without throwing the whole into confusion.

Of other systems than our own, little is yet discovered. It is supposed that each *fixed star is a sun*, and the center of its own system of worlds.

Our system is called the *solar system*, and consists of the *sun* with its *planets*,* and their attendants, called satellites or *moons*.

The Sun.

692. The *sun* is the *center of the solar system*, and the *source* of *light* and *heat*. It is the *center of attraction* which connects and binds together the whole solar system. Its *magnitude* is more than a million of times greater than that of the earth; and it is ninety-five millions of miles *distant* from it. The sun was long supposed to be an immense globe of fire. Some eminent astronomers of the present day believe it to be an opaque body surrounded by a highly luminous atmosphere. What it is, we know not. As its great Creator pervades every place throughout the universe, and yet has his seat in the heavens, so the sun, by his rays, is in all places throughout the solar system, while he is fixed in the center of that system. The sun, like the earth, *revolves on its axis*, and completes one revolution in 25 days. This is proved by observing certain remarkable spots on the sun's disc. These spots are seen to appear and disappear at regular intervals, which can only be accounted for by supposing a rotation on its axis.

The sun, if viewed from any other system in the universe, would appear, to beings with the same optical powers as we possess, as a fixed star does to us.

The Planets.

693. Between the earth and the sun are two planets, *Mercury* and *Venus*. These are called *inferior planets*, because their or-

* From the Greek *planetes*, wandering or moving.

691. Opinions of astronomers with regard to the universe. Solar system.
692. The sun. Magnitude of the sun. Revolution of the sun. Probable appearance of the sun at other systems.
693. Inferior planets. Mercury. Venus. Transit of Venus.

bits are nearer the sun than is the orbit of the earth, or, in other words, they are within the earth's orbit.

Mercury is the most rapid in its motion of all the planets, and, for this reason, was named by the ancient heathen after the swift messenger of the gods.

Venus, during one part of the year, is Lucifer, or the morning star, and at another portion of the year, Hesperus, or the evening star. She is the morning star when seen westward of the sun, for she then rises before that luminary. She is the evening star when seen eastward of the sun, for she then sets after him. As the orbit of Venus lies between the earth and the sun, it follows that when she passes across the sun's disc, a dark round spot appears to as on that luminary. This is called the *transit** of Venus, and has occurred only twice in about 120 years; the last time was the 3d of June, 1769. In the present century there will be two transits of Venus; one in the year 1874, and the other in 1882. By the observation of this phenomenon many important astronomical calculations have been made.

694. The *Earth* is the third planet in the solar system. To an inhabitant of Venus our planet would appear much as Venus does to us.

Looking on our earth as a star in the solar system, we are at once undeceived as to the apparent motions of the heavenly bodies around it. Can we suppose that the vast orb of the sun, with the planets in its system, some of which are much larger than the earth, are all satellites to our little world? Reason smiles at the supposition, and philosophy pronounces it impossible. The smaller body, according to the principle of gravitation and the laws of motion, must revolve around the larger.

The *moon* is a satellite of the earth. Like the other heavenly bodies it daily alters its apparent position, and, in the course of a month, appears to make a complete revolution round the heavens from west to east, while, at the same time, it has, like the fixed stars, an apparent, daily motion from east to west. Of all the celestial luminaries, this is the nearest to us, its mean distance being about 237,000 miles. When the moon, in her revolution in her orbit, passes between the sun and the earth, the sun's light is partially or totally hidden from the earth, and this is called an *eclipse of the sun*;—when the moon falls into the earth's shadow, so that she is not enlightened by the sun, an *eclipse of the moon* is caused.

695. The planets in the solar system whose orbits are beyond that of the earth, are called *superior planets;* these are *Mars, Jupiter, Saturn* and *Herschel*, with four smaller, and lately discovered planets, called *asteroids*.

* From *trans*, passing over.

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694. The earth considered as a star in the solar system. The moon and her revolutions. Cause of an eclipse of the sun. Of the moon.

695. *Superior planets.* Mars. Jupiter. Eclipses of his satellites.

Mars has no satellite, and is known by his deep red color.

Jupiter is the largest of all the planets, and is attended by *four moons* or satellites. He is distinguished in the heavens for his magnitude and brightness, being scarcely less bright than Venus. When examined through a telescope his surface seems shaded by stripes. Some astronomers suppose these to be the effect of changes in the atmosphere of the planet; others that they indicate some great physical changes which are taking place on its surface. By the eclipses of Jupiter's satellites, light, which was formerly supposed to move instantaneously, is found to have a *progressive motion*. By observations upon these eclipses, with the help of optical instruments, the mariner, when other means fail, may determine the degree of longitude.

696. *Saturn* shines with a pale light; he is attended by seven moons, and is remarkable for being surrounded with a double ring, more luminous than the planet itself. This ring revolves around the planet, it is more than 33,000 miles broad, and not quite 300 miles in thickness, so that it resembles a broad plane. No part of its surface is nearer than about 2300 miles to the surface of the planet. From its great extent, we may reasonably believe it to be a world of itself, and peopled with intelligent beings.

697. *Herschel*, sometimes called Uranus,* and Georgium Sidus,* was discovered as late as 1781, by the celebrated astronomer, Dr. William Herschel, who with his sister, Miss Caroline Herschel, and his son, Sir John Herschel, form a constellation of talent in the department of astronomy. The planet Herschel is so immensely distant from this earth as to be scarcely visible without a telescope. It has *six moons* or satellites. Beyond the orbit of Herschel no planets have yet been discovered in the solar system.

698. The *asteroids* revolve around the sun in orbits which are between the orbits of Mars and Jupiter. They are called Vesta, Ceres, Pallas and Juno.

Comets.

699. *Comets* are bodies which move around the sun in very long elliptic curves, sometimes approaching near the sun, and then

* Uranus, in mythology, is the father of Saturn. Georgium Sidus, literally the Georgian star, was a name given by Dr. Herschel, in compliment to his sovereign, George III, King of Great Britain.

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696. Saturn. His ring.
697. Herschel. When discovered.
698. Asteroids.
699. Comets. Enke's comet. Comet of six year's period. Halley's comet.

travelling far beyond the orbit of the most distant planet. Among hundreds of comets which have at different times been visible, the revolutions of three only, have been determined with any degree of accuracy. One of these called Enke's comet, has a period of three years and 112 days; it is very small, and seldom visible to the naked eye. Another comet, which has a period of six years and three-fourths, appeared in 1822. Halley's comet appeared in 1835. The great astronomer whose name it bears, ascertained the period of its revolution to be about 75 years, sometimes a fraction of a year more, and sometimes less. For the astronomer in computing the motions of comets must take into the account, besides the usual rate of motion in different parts of their orbits, the delays which they may receive from the attractive forces of the various celestial bodies, within whose spheres of influence they may happen to fall. Thus Halley's comet, in one of its revolutions round the sun, was delayed or retarded one hundred days while within the sphere of attraction of the planet Saturn, and five hundred and eighteen days while within that of Jupiter.

700. Comets are accompanied by a train of light resembling illuminated hair,* called the tail of the comet. By some, the comet itself is supposed to be a nucleus of vapors, and the train or tail, which appears somewhat like the *aurora borealis*, to have its origin, as that meteor is supposed to have, in disturbed electricities. But nothing certain is known as to the physical constitution of these bodies. If comets are peopled, the beings who inhabit them must be fitted to endure the greatest diversity of climate; from the burning heat of the sun when nearest to that luminary, to the total absence of heat, when traversing the distant and utmost boundaries of the solar system. They must endure also, the change of being sometimes carried onward with a velocity almost equal to that of a ray of light, and then ith the slow pace with which the comet moves in the utmost point of its orbit.

Proportional Magnitude of the Planets.

701. The Earth is fourteen times as large as Mercury, very little larger than Venus, and three times as large as Mars. The diameter of Jupiter is $11\frac{1}{8}$ times greater than the diameter of the earth; its surface is 118 times, and its bulk 1281 times greater

* Whence the name, from the Latin *coma*, a hair.

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700. Comet's train. Physical constitution of comets.

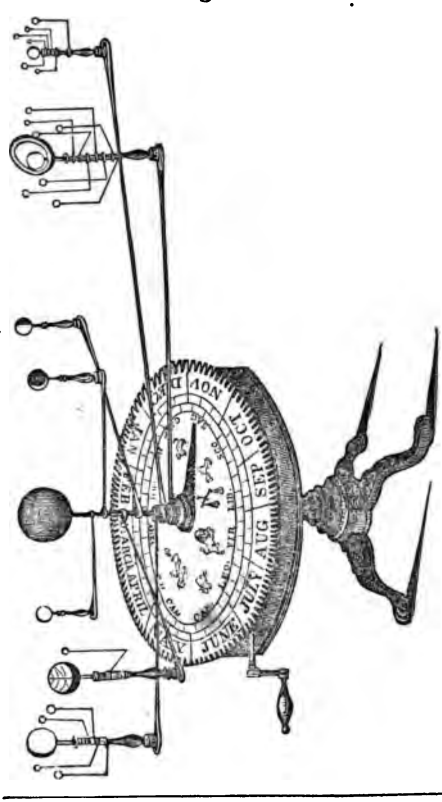
701. State the comparative magnitudes of the planets. State the distances of the planets from the sun. In how long a time would a cannon ball moving at the rate of eight miles a minute go from the sun to Mercury, &c.

than that of the earth. The bulk of Saturn and his ring united is more than 1000 times greater than the earth. The surface of Herschel is 19 times larger than the earth, but this planet is much less solid, so that its quantity of matter is only about seventy-eight times greater than that of the earth.

Distances of the Planets from the Sun, in miles.

Mercury,	37,000,000	Juno, Ceres, Pallas,	261,000,000
Venus,	68,000,000	Jupiter,	490,000,000
Earth,	95,000,000	Saturn,	900,000,000
Mars,	143,000,000	Herschel,	1,800,000,000
Vesta,	225,000,000		

Fig. 274.



That we may more easily comprehend the vast distances of the planets from the sun, some rule or measure, adapted to the capacity of our senses, must be resorted to. Thus, reckoning the velocity of the cannon ball, at 8 miles a minute, it would go from the sun to Mercury in 9½ years; from the sun to Venus in 18 years; to the Earth in 25 years; to Mars in 38 years; to Vesta in 60 years; to Juno in 66 years; to Ceres and Pallas in 69 years; to Jupiter in 130 years; to Saturn in 238 years, and to Herschel in 479 years. A cannon ball with the stated velocity, would go from the earth to the moon in 23 *days*.

702. By means of an *orrery* is represented the motion of the planets a-

702. Explain the orrery.

round the sun, and that of the satellites around the *primary* planets, with their comparative magnitudes and distances.

On the upper plate, which answers to the ecliptic, are placed, in two opposite but corresponding circles, the days of the month, and the signs of the zodiac with their respective characters. By this plate, the planetary balls may be so set as to be in their proper places on the ecliptic for any day in the year. A brass ball in the center represents the sun, this is supported by a brass rod which passes through the center of the plate, and has sockets for supporting the arms by which the several planets, with their satellites are supported. The planets are represented by ivory balls, having the hemisphere which is towards the sun white and the other black, to represent their different phases. The moons or secondary planets are arranged in the proper order around the primary planets.

By turning the handle of the orrery, a train of wheel-work, which is concealed in the circular brass box under the upper plate, is set in motion. The planets revolve around the sun in the center, and the moons revolve around the planets. To give a more perfect representation of the solar system, the planets with their respective moons, should have a rotary motion on their axes.

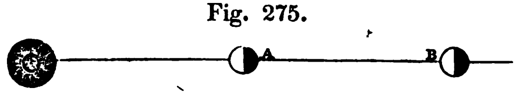
703. Instead of a motion from east to west, which the celestial bodies appear to have, they actually revolve around the sun, and upon their own axes, from west to east. The earth also revolves in the same manner. This motion of the earth from west to east, makes the sun appear to us to move around us in a contrary direction; as when we start in a steamboat from New York to go up the Hudson, the city itself appears to be moving southwardly, when, in reality, it is our own motion towards the north which causes this appearance.

Application of Mechanical Laws to Planetary Motion.

704. *The attraction of gravitation is in proportion to the quantity of matter.* The sun being the largest body in the solar system, *attracts* the planets, and they, in turn, *gravitate* or tend towards the sun.

705. *Attraction decreases, as the squares of the distance increase.* Suppose a planet at B, to be *twice* as far from the sun as

Fig. 275.



at A; then, as the square of the distance 2×2 is 4, the attraction at B will be four times less than at A, or which is the same thing, the planet at A will be attracted with four times the force it would be at B. But if the distance of A from the sun were *four* times less than that of B, then as the square of 4×4 is 16, the attraction at A would be sixteen times greater than at B.

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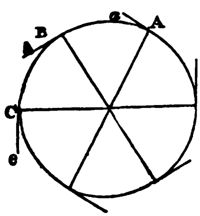
703. Real motion of the celestial bodies. Motion of the earth.
704. Law of gravitation. The sun and planets mutually attracted.
705. Decrease of attraction.

706. Since the planets are attracted towards the sun with a force proportioned to his quantity of matter, and their respective distances, why, it may be asked, do they not fall upon the sun, as bodies attracted by the earth, fall upon its surface? To solve this question, you will have occasion to recall what has been said of the effect of motion produced by two forces. Motion produced by one force, you have learned, is in a straight line; but the planetary motions, in their orbits, are *circular*. The planets do not fall upon the sun, because there is, in operation, another force besides that of gravitation which affects their motion. This is the *projectile* or centrifugal *force*, while the sun's attraction is the *centripetal force*; the joint action of these forces, produces the circular motion of the planets, and keeps them in their orbits. Thus, suppose a stone whirled around in a sling; we have a circular motion resulting from two forces; 1st. the projectile force which was first given it by the arm, and 2d. the central force, or that with which it is held by the string. If the stone flies out of the sling, the projectile force alone would then act, and the stone would move from A to *a*, or in a *tangent* to the circle; if let go at B, the stone would move in the tangent B *b*, or at C, in the tangent C *c*.

Fig. 276.



By this law, the moon moves round the earth, and the earth and other planets move round the sun; the projectile force and the force of gravitation being so nicely balanced, as to retain them in their orbits. Should one of these forces cease, the other would then act alone, the projectile force unbalanced, would carry the earth, in a straight line, off into infinite space; while the force of gravity alone would cause it to fall upon the sun.

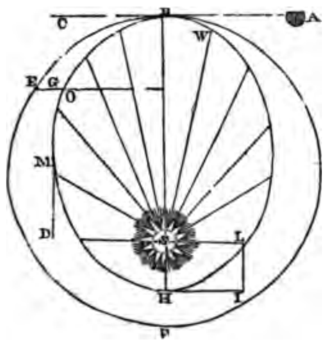
707. The orbits of the planets are not perfect circles, but ellipses or ovals, that is, having greater length than breadth, and with two central points, called *foci*. Suppose a planet, A, (Fig. 276,) moving by its projectile force towards B, if it met with no resistance, it would forever move on in a straight line, and would pass in equal times over equal spaces, that is, from B to C in the same time as from A to B, and so on. But at B, it is acted on by a new force, viz., the sun's attraction in the line S B. The two forces acting at the right angle A B S would, if equal, cause the planet to revolve in

706. Circular motion of the planets, how produced. Effect of disturbing either of the two forces which keep the planets in their orbits.

707. Elliptical orbits of the planets. Explain the motion of a planet in its orbit.

the circle B E F; but the sun's attraction being more powerful than the projectile force, the planet is brought nearer the greater force, and describes the curve B G. Now at G the angle O made by the two forces is less than the right angle, in conseqence of the forces acting more in concert, the motion in this part of the planet's orbit is acellerated; and further, as the distance of the planet from the sun *decreases*, attraction increases. At the point M, the increased velocity has increased the centrifugal force so much, that the planet would be impelled in a tangent towards D, were it not that the force of attraction is constantly becoming greater. Thus the motion of the planet is uniformly accelerated from B to H. At H the projectile force is so great that it would impel the planet to I, while the attractive force would draw it towards S, but the joint action of the two forces carries it to L. In passing from H to B, or in going from the sun, its motion is retarded in the same degree that it was accelerated from B to H, so that at H or nearest the sun, the velocity is greatest, while at B it is least.

Fig. 277.



708. Thus the elliptical orbits of the planets are caused by a projectile force, and the repeated action of gravitation which draws the body from a true circle. A circle has within it one central point, which is equally distant from every part of its circumference; but an ellipsis has *two* central points called *foci.**

The sun (Fig. 277) is in the lower focus of the ellipsis B G H. When the planet is nearest the sun, as at H, it is said to be in its *perihelion;* when most distant, as at B, in its *aphelion.*

709. If the attractive powers of the sun were uniformly the same in every part of the orbits of the planets, they would *pass over equal spaces in equal times.* But on account of being more attracted in some parts of their orbits than in others, the planets pass over *unequal portions of their orbits in equal times.* But the *areas* which are included in those spaces are equal, that is, the area of the triangle B S W, is equal to the area of the triangle

* Plural of focus.

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708. Cause of the elliptical orbit of the planets. Foci of an eclipse. Perihelion. Aphelion.

709. Explain what is meant by the planets passing over equal spaces in unequal times.

L S H, although the arcs which subtend these triangles are unequal. If the twelve triangles made by the lines proceeding from the circumference B M H to S be considered as representing the twelve months in the year, we perceive that the spaces through which the sun passes will be increased each month for one half of the year, and proportionally diminished the other half, though the areas passed over in each month are equal. It is one of the great laws of planetary motion, that the planets, in *their revolutions, describe equal areas in equal times.*

710. The secondary planets in their revolutions round their primaries, are governed by the same laws as those which cause the revolutions of the primaries around the sun. Thus the *moon*, being within the sphere of the earth's attraction, and acted upon also by a projectile force, is retained in her orbit, and continues to revolve around the earth. The secondary planets move with their primaries around the sun.

711. It is conjectured that the sun himself, with his retinue of eleven primary planets, and eighteen satellites, sweeps around some GRAND CENTER towards which *solar systems* gravitate, as planets gravitate towards their center! But in pursuing such suggestions,

> "Imagination's utmost stretch,
> In wonder dies away."

LECTURE XLI.

FIXED STARS.—CONSTELLATIONS.—GALAXY.—NEBULÆ. CONCLUDING REMARKS.

712. We have briefly noticed the bodies which compose the solar system, or that family of worlds with which our own is connected. But these worlds are few in number, compared with the whole glorious company of celestial bodies, which we behold with the unassisted eye, when looking at the heavens in a clear night. The planets shine with a steady light, while the fixed stars are distinguished by their twinkling. The light of the moon is more steady and mild than that of the sun; the cause perhaps is

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710. Revolutions of the secondary planets.

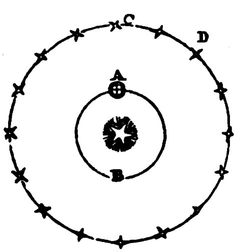
711. Probable revolution of the whole solar system.

712. Bodies in the solar system few in comparison with the whole number of stars seen by the naked eye. Light of the fixed stars and planets.

that the moon shines by reflected light, and the sun by its own powerful rays. The planets are all moons to us in respect to the reflection of light. The fixed stars are supposed to be all suns, shining with their own beams. The twinkling of the fixed stars is by some ascribed to the refractions and reflections produced by a variety of atmospheres. The planets seem as large, or larger than the fixed stars, because they are comparatively very near us.

713. All the celestial bodies beyond our system are called *fixed stars*, because they do not appear to change their places in the heavens as the other planets do. This fixed appearance is probably owing to their immense distance from the earth. The orbit of the earth is twice ninety-five millions of miles across, and we are therefore one hundred and ninety millions of miles nearer to some stars at one time than at another, yet they always appear to be in the same places; that is, the star which we see in the north, is always seen in the same latitude in the heavens; that which we see at one time near the equator of the heavens, is always seen so, and that which we see in the south never appears in the north.

Fig. 278.



If the circle A B represents the earth's orbit, the earth at A will be one hundred and ninety millions of miles nearer to the fixed star C, than it will be at B, and yet the magnitude of the star does not seem diminished by this distance, nor should we perceive any change in its position, if in reality it were to move from C to D, because this change would be nothing in comparison to the distance of the star from the earth. Two stars which seem to be very near each other, may be millions of miles distant, or one may be far beyond the other in the depths of space. The *apparent* motion of the stars from east to west, is caused by the earth's motion on its axis from west to east.

714. The fixed stars, are supposed to be, like the sun of our system, centers of attraction around which revolve worlds with their attendant moons, and eccentric comets. These systems may be revolving in the immensity of spac , but if so, our own is also pursuing the same round, and thus the relative positions of each are maintained.

715. The stars have been arranged by astronomers according

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713. Fixed stars appear stationary. The cause of this appearance illustrated.

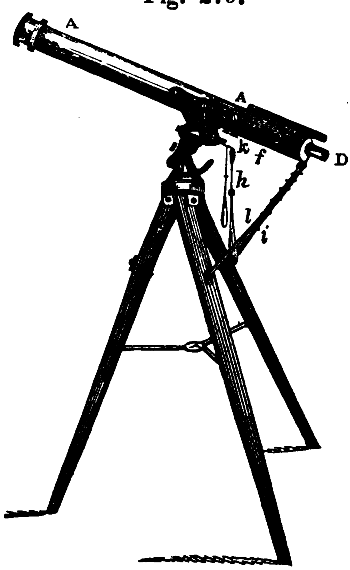
714. Fixed stars supposed to be suns.

715. Classes of stars according to magnitude. Sirius.

to their magnitudes and apparent brightness, into six classes. Thus *Sirius*, or the dog star, is said to be a star of the *first magnitude*. It is estimated, by some very nice calculations of Dr. Wollaston, that if this star were placed where the sun is, he would appear to us three times as large as that luminary, and give more than thirteen times more light. It is supposed that many of the fixed stars must be millions of times larger than Sirius. These are calculations indeed which almost overwhelm the reason of man! They should humble that arrogance which seeks to find out "the hidings of Almighty power," and refuses to believe what human reason cannot comprehend.

716. Stars of the *sixth magnitude* are the smallest which can be seen without a telescope. They may, in reality, be much larger than those that appear to us of the first magnitude; their diminished size being the effect of their immeasurably greater distance. By the naked eye, only about two thousand stars are visible, though when we look at the heavens in a clear star-light night, their number seems beyond the power of computation. But this is an optical illusion, arising from the countless reflections and refractions to which light from the stars is subject before it reaches us. On looking at a star of the first magnitude through a long narrow tube, the star will appear scarcely visible; this shows that very few direct rays of the stars reach us, but that the brilliancy of the heavens is greatly owing to the reflection and refraction of light.

Fig. 279.



717. The *astronomical telescope* has revealed the heavens under a new aspect. Our solar system has been enriched with new planets, the satellites and Saturn's rings

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716. Stars of the sixth magnitude. Number of stars visible to the naked eye. Cause of their appearing more numerous than they really are.

717. Discoveries by means of the telescope. Parts of the astronomical telescope. Why objects seen through the telescope appear magnified. The moon seen under an angle of fifty degrees.

have been discovered, and the moon's surface is found to be diversified by mountains and plains.

Fig. 276 represents a refracting telescope fitted up for astronomical observations, in the manner practised by astronomers. Suppose A A to be a large tube, into which is inserted the small brass tube D, containing the eye-glasses. The object-glass is fitted to the upper end of the large tube; *h k* are two handles for adjusting the instrument, and *i l* are for the purpose of keeping it steady. In considering the subject of optics, we noticed the construction and operation of telescopes. The glasses, or *lenses*, are so formed, that objects seen through them appear at a greater angle than when viewed with the naked eye; this causes them to *appear larger* and *nearer*. The moon when viewed by the naked eye, appears under an angle of about half a degree; therefore a telescope which represents it under an angle of fifty degrees, magnifies one hundred times.

718. "The first result of the invention of the telescope, and its application to astronomical purposes by Galileo," says Sir John Herschel, "was the discovery of Jupiter's disc and satellites,—of a system offering a beautiful miniature of that greater one of which it forms a portion, and presenting to the eye of sense, at a single glance, that disposition of parts which in the planetary system itself, is discerned only by the eye of reason and judgment. We have here in miniature, and see at one view, a system similar to that of the planets about the sun."

The Constellations.

719. There has ever been in the mind of man a tendency to generalize and classify. Minerals, plants, and animals are grouped together according to certain principles of resemblance. A collection of families is called a town, and many towns form a state. Even savages group themselves together in tribes. Following this bent of the human mind to generalize and classify, the priests and learned men of ancient Egypt, under their serene and cloudless sky, and the ancient herdsmen and shepherds while tending their flocks and herds by night upon the plains of Chaldea and Babylon, observing the stars clustered together in groups, began to parcel out the heavens into various divisions, which they called *constellations*, and which they named according to their own peculiar fancies.

720. In the book of Job, (which is considered one of the most ancient of the Holy Scriptures,) the constellation Orion, and the Pleiades, are named, with "Arcturus and his sons." Orion is perhaps of all the constellations visible in a winter's night, in our

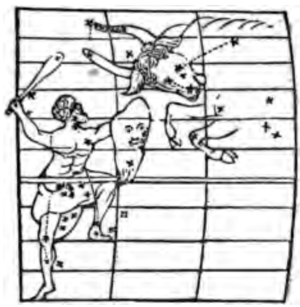
718. First application of the telescope to astronomy.

719. Tendency of mankind to form classes. Origin of the arrangement of stars in constellations.

720. First mention of constellations. Orion. How represented on the celestial globe. Appearance of Orion in the heavens. Principal stars in Orion. Bands of Orion. Triangle in the head of Orion, &c. Discoveries made by the telescope in the constellation Orion. The Pleiades. The Hyades.

hemisphere, the most brilliant and the most generally known. Not perhaps so well known by its scientific name, as by that of the "*yard and ell*," and sometimes the "*three stars*." Many a thoughtful youth pauses in his winter sports upon the ice, to contemplate this grand constellation, as it spreads itself across the eastern sky. In spite of the mirth of his noisy companions, his soul is filled with inquiries as to the nature of those bright orbs, and the part they are fulfilling in the economy of the universe!

Fig. 280.



Orion is represented (see Fig. 280,) by the figure of a warrior, with a sword in his belt, a club in his right hand, and the head and skin of a lion in his left, for a shield. He seems to defend himself from the bull, the figure of which is represented in the constellation Taurus. Orion begins to appear in the eastern horizon, before nine o'clock in the evening, in the early part of winter. Every evening he is seen higher and higher in the heavens, until, on the 24th of January his most northern star appears on the meridian; the center of the constellation is directly over the equator of the earth, and half way between the poles of the heavens. Four bright stars in the form of a parallelogram form the outlines of the constellation. The two upper stars are considered as epaulets upon the shoulders of Orion, the western of the two lower stars is upon his left foot, the other upon his right knee. But this constellation is remarkably distinguished by the three bright stars in a row which form the *belt of Orion.* They are in the middle of the parallelogram; and they are beautifully described in the book of Job, as the *bands of Orion.* "Canst thou loose the bands of Orion?" inquired the Almighty, of his presumptuous servant! The three stars in the belt measure just three degrees in the heavens, and extend from north-west to south-east.

In the head of Orion, is a *triangle* of three small stars, which form a large triangle with the two in his shoulders. The two upper stars in the parallelogram are about 15 degrees north of the lower ones. The name of the star in the left foot on the west is Rigel; it is a star of the first magnitude, as is also the star on the east shoulder. The stars on the belt are of the second magnitude, those in the sword of the fourth and fifth magnitude.

All that we have described of Orion, is plainly to be seen with the unassisted eye. But the telescope has revealed more than two thousand stars in this one constellation. One single star in the sword has been multiplied to twelve; and in the belt no less than eighty stars have been discovered. Imperfect as the best instruments are, and almost infinitely distant as is this constellation from us, how absolutely unlimited seems the number of stars which are clustered together in this *neighborhood!* A neighborhood of stars of which the nearest are millions of miles distant!

The Pleiades, or *seven stars*, are a cluster which lie in the *shoulder* of Taurus, (the Bull,) to the north-west of Orion; they

appear on the meridian a few minutes before 9 o'clock, on the first of January. The sun enters this cluster of stars in the spring, or season of blossoms, hence the inquiry of Job, "Canst thou bind the sweet influences of the Pleiades?" In this cluster of seven stars, as seen by the naked eye, more than two hundred stars have been discovered by the aid of the telescope.

The Hyades are in the head of the Bull, eleven degrees south-east of the Pleiades. The cluster is composed of five stars, so situated as to form the letter V. In this cluster is the red star Aldebaran, a star of the first magnitude. The constellation Taurus, or the Bull, is represented as only exhibiting the head and shoulders of the animal.

721. The heavens are divided by astronomers into three regions. The *northern* and *southern* portions, and the Zodiac.* The Zodiac is a zone or girdle in the middle of the heavens, sixteen degrees broad, or eight degrees on each side of the ecliptic. The orbits of all the planets are within this zone. The ecliptic is the earth's orbit, or line described by the earth's annual revolution round the sun. In ancient times, long before men had any true notions of astronomy, they supposed the sun moved around the earth, as indeed on account of the earth's motion it *appears* to do; and observing that at different seasons, it appeared in different clusters of stars, they called these *the signs of the Zodiac.*

Constellations in the Zodiac.

722. The first astronomers seeing the sun in March always rise with a particular cluster of stars, called this cluster the constellation *Aries*, (the ram;) thus they said the sun is in *Aries* in March. In April the sun rose in another constellation, which they called *Taurus*, (the bull;) and in May it rose in the constellation called *Gemini* (the twins.) These were the *spring months;* and the names given to the constellations, were perhaps on account of some fancied resemblance of their outline, to the objects after which they were called; or from some relations of analogy connected with their agricultural or other pursuits, at the times when the sun successively rose with the twelve signs of the Zodiac. Thus the first signs, Aries and Taurus, are named after the animals which the shepherds and herdsmen, who were probably the first observers of the stars in reference to their influence upon

* From the Greek *Zodiakos*, signifying an animal. The 12 signs of the Zodiac being represented by 12 animals.

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721. The heavens divided into different regions.

722. Signs of the Zodiac. Signs which distinguish the spring months. Why were these signs thus called?

the seasons, held in the highest esteem; and the third might have been named in allusion to the *twin season* of their flocks.

723. In this manner was parcelled out the Zodiac into *twelve parts or signs*, each sign spread over thirty degrees of the heavens, or the twelfth part of three hundred and sixty degrees.

724. This division of the Zodiac into twelve parts was arbitrary; and although the constellations have somewhat changed their places during the lapse of so many centuries the signs still remain in the same order as numbered by the Chaldean shepherds; but the signs do not answer to the same points; and the stars, which were then in conjunction with the sun when he was in the equinox are now a whole sign, or thirty degrees, to the eastward of it; so that the first star of Aries is now in the portion of the ecliptic called Taurus; and the stars of Taurus are now in Gemini, and those of Gemini in Cancer, and so on. By this retrograde motion, the pole, the solstices, the equinoxes, and all the other points of the ecliptic, have a retrograde motion, and are constantly moving from east to west, or from Aries towards Pisces, at the rate of about fifty seconds and a quarter each year, which is called the *precession of the equinoxes*. This rate of retrograde motion being constant, it will require twenty-five thousand seven hundred and ninety-one years for the equinoxes to make their revolutions westward quite around the circle, and return to the same point again.

725. In June the sun enters the 4th sign, *Cancer*, (the crab.) Here he ceases to advance northward, but begins to go back towards the equator. This retrograde motion might have suggested the name of an animal which is said to move by going backwards. In July the sun enters the fifth sign, *Leo* (the lion;) at which time the heat of the sun was lion-like, that is, strongest and fiercest over the regions of Chaldea and Egypt. The sixth sign is *Virgo*, (the virgin,) represented as a female reaper. The sun enters this sign in August, the harvest month. In September when the sun is in the sign *Libra*, (the balance,) the days and nights being equal, balance each other. This is the seventh sign. The sun enters the eighth sign, *Scorpio*, (the scorpion,) in October, when the autumnal *fruits* having engendered diseases, the season may be compared to the poisonous reptile which bears a sting in his tail. In November the sun enters the ninth constellation, represented by *Sagittarius*, (the archer.) The season when beasts of the chase are in flesh, and when men take delight in hunting. The tenth sign of the Zodiac, *Capricornus*, (the goat,) is the emblem of the

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723. Twelve signs.

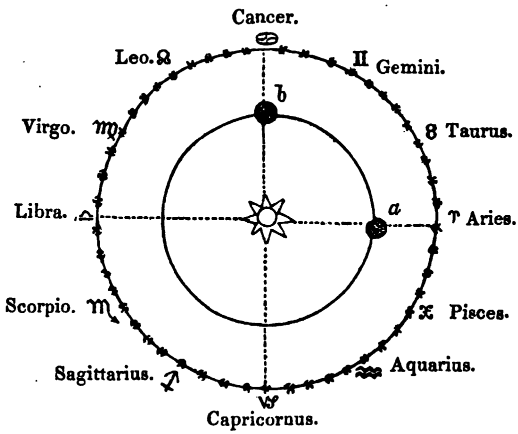
724. Precession of the equinoxes.

725. When is the sun in Cancer? Leo? Virgo? Libra? Scorpio? Sagittarius? Capricornus? Aquarius? Pisces?

winter solstice, when the sun turns about, as it were, and, from the southern tropic, begins to climb towards the equator. The sun is in this sign, six months after he has, like the crab, began his retrograde motion from the sign or tropic of Cancer. The eleventh constellation on the Zodiac, is named *Aquarius*, (the water bearer.) It is represented by the figure of an old man in the act of emptying an urn of water. The season of humidity, fast hastening to its close. In February the sun rises with the constellation *Pisces* (the two fishes ;) indicating the fishing season, when the earth is bound in frost, the seas offer their stores for the sustenance of man. This is the twelfth sign of the Zodiac, and closes that great circle of the heavens.

726. When the earth is in that part of her orbit represented in the figure at *a*, a right line from the earth to the sun, and extended to the fixed stars, would pass through the sign Libia, thus the sun would appear as if situated in that constellation. When the earth is at *b*, the sun will appear to be in the sign Capricornus.

Fig. 281.



727. Besides the twelve constellations of the Zodiac, there are reckoned about thirty-five constellations in the hemisphere north of that plane, and forty-five south of it.

The Little Bear, (*ursa minor*,) is a constellation situated near the north pole of the heavens ; from its being almost at the axis of motion, it scarcely has any revolution, and always appears

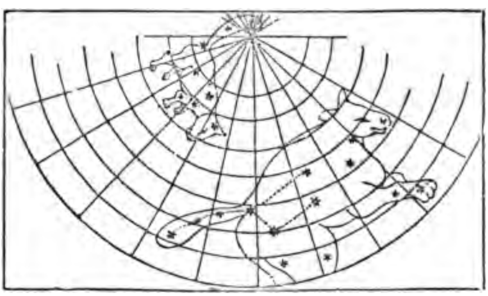
726. Explain what is meant by the sun being in any constellation.
727. Number of constellations besides those of the Zodiac. Ursa minor. Polar star. Arcturus with his sons. Mazzaroth.

above the horizon. In the tail of this constellation is the ***North Star***, sometimes called the *polar star*. It is a star of the third magnitude, and not remarkably brilliant.

The polar star is easily found by its being in the neighborhood of the constellation known commonly as the *Dipper*, (the Great Bear, or Ursa Major.) In this constellation, four bright stars in the body of the bear form the bowl, and the three in the tail form the handle. There are two stars opposite the handle of the Dipper, called the *pointers*, because they always point to the north pole of the heavens, from which the polar star is nearly two degrees distant. Several degrees west of the Dipper is a bright star of the first magnitude called *Arcturus ;* it is in the constellation *Bootes*, or the *Bear Driver*, so called because it seems to be pursuing the Great Bear around the pole. "Canst thou guide Arcturus with his sons, or bring forth Mazzaroth in his season ?" inquired the Most High of Job. Arcturus, being the leading star of Bootes, seems here to refer to the whole constellation. *Mazza-*

Fig. 282.

North Pole of the Heavens.



roth is supposed to be a general term for the constellations of the Zodiac, which, by being *brought forth* in their respective months, cause the varieties peculiar to the different seasons.

728. No young person should remain ignorant of the names and places of the most remarkable constellations and stars. It is as easy to find the place of Orion in the heavens, as it would be at Rome to find the situation of St. Peter's church ; and as for "The Dipper," there are few children who have not had it pointed out to them. That brilliant star of the first magnitude, situated south and east of Orion, in the constellation of the Great Dog, called Sirius, or the Dog star, is always viewed with pleasure and delight, even by the vulgar and uninstructed. This beautiful star, although

728. Study of the constellations easy and pleasant.

not often seen by us except in winter, is, in reality, over our heads during the day in mid-summer, rising with the sun during a month, from the 24th of July to the 24th of August. The heat, which is usually most oppressive at this season, was formerly ascribed to the conjunction of this star with the sun. And the distinctive name "*Dog days*," is still given to this season.

729. The *Milky Way*, or *Galaxy*, is a luminous zone in the heavens, of a dazzling whiteness. It was long a question with astronomers what occasioned this broad arch of light across the sky. But at length Sir William Herschel, aided by his great telescope, proved that this brightness was the *combined effect of myriads of stars*, so distant that their image is lost to us. This celebrated astronomer counted not less than fifty thousand stars, which passed through the field of his telescope in a zone of the heavens two degrees broad.

730. *Nebulæ*, are spots in the heavens, which even with ordinary telescopes, appear but as white clouds, or masses of unformed light. When examined by the best telescopes, they give the idea of a concave space filled with stars, insulated in the heavens, and constituting systems of their own. "To attempt to count the stars," says Herschel, "would be hopeless;" but he thinks many clusters of this description contain no less than twenty thousand stars, compacted into a space not one tenth as large as the moon's apparent surface. "If each of these stars," says Mrs. Somerville, "be a sun, and if they be separated by intervals equal to that which separates our sun from the nearest fixed stars, the distance which renders the whole cluster scarcely visible to the naked eye, must be so great, that the existence of this splendid assemblage can only be known to us by light which must have left it at least a thousand years ago.

731. The study of the starry heavens is an elevating and noble pursuit, introducing us to a knowledge of God, in the contemplation of his most sublime and glorious works. From the earliest periods of time it has added warmth to devotion, and to poetry its happiest inspirations: Thus Euripides, the Greek poet, in his drama of Ion:

> Meanwhile the Night, robed in her sable stole,
> Her unrein'd car advances; on her state
> The stars attend; the *Pleiades* mounting high,
> And with his glittering sword *Orion* arm'd;
> Above, *Arcturus* to the golden pole
> Inclines; full-orbed the month-dividing moon
> Takes her bright station, and the *Hyades*
> Marked by the sailor.

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729. Galaxy.
730. Nebulæ. Opinion of Herschel. Remarks of Mrs. Somerville.
731. Observations upon the study of the heavens.

732. Having indulged imagination in wandering through the solar system, and the more remote regions of space, as far as the human intellect has yet dared to penetrate, we must now return to our own little planet. The earth, indeed, appears insignificant when considered in relation to this vast universe, and even to the system of which it forms a part. Among the family of worlds which move around the common center of attraction in the solar system, our planet is but an inconsiderable member. If Mars and Mercury are of less magnitude, the far distant Herschel, with his numerous satellites, Saturn with his splendid rings, and attendant moons, and the magnificent Jupiter with his retinue of worlds, all fill a far greater extent of space, and must offer to the view of a spectator situated in some central point, an appearance far more grand and imposing than earth with her diminutive size, and the one little ball revolving around her. Let us learn a moral lesson from the stars ;—we see that God has not made them all alike, but "that one star differeth from another star in glory," yet each harmoniously fulfils its destined round in the economy of nature. So it is with us, the beings who inhabit the little planet, called earth. Some have more wealth than others, some have greater intellectual power, some are lifted up, and some cast down ; but all should harmoniously move on in their assigned orbits, trusting that he who placed them there, knows best how to order his own creation. And again, there are always some compensations, which may be set off against disadvantages—thus the earth, though not great like Jupiter, nor like him followed by a train of attendants, is favored with more warmth and light, as the lowly man is often peculiarly favored with spiritual enjoyments, and the light of God's countenance.

733. But our connection with the earth we now inhabit, is to be of short duration ;—we may move upon it for a little while, and then our ashes will repose in its bosom until that day, " when the heavens will be rolled together as a scroll, and the earth shall melt with fervent heat." Under new and glorious forms, we shall then be translated to regions free from sin and sorrow; our celestial bodies will have power to range through the infinity of creation, and our souls will be delighted with the contemplation of glories which mortal eye hath not seen. But that we may be thus happy, thus blessed, we must here cultivate the better faculties of our nature, and make our intellectual attainments subservient to moral elevation. The rays of science, collected into a focus by religion, and directed towards the heart, cannot fail to warm and animate it with new love towards God, the Father of our spirits and the Author of Nature.

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732. The earth compared with other heavenly bodies.
733. Conclusion.

THE END.

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